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(54) MIXED POWDER FOR IRON-BASED POWDER METALLURGY AND SINTERED BODY PRODUCED USING SAME

(57) The mixed powder for iron-based powder metallurgy of the present invention comprises: at least one ternary oxide selected from the group consisting of Ca-Al-Si oxides and Ca-Mg-Si oxides, and at least one binary oxide selected from the group consisting of Ca-Al oxides and Ca-Si oxides. The ternary oxide and the binary oxide are contained in a sum weight of 0.025 wt% or more to 0.3 wt% or less.

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Description

Technical Field

[0001] The present invention relates to a mixed powder for iron-based powder metallurgy and a sintered body prepared by using the same, and more particularly to a mixed powder for iron-based powder metallurgy containing binary oxides and ternary oxides at a specific weight ratio and a sintered body prepared by using the same.

Background Art

[0002] Powder metallurgy is widely used as a method for industrial production of various kinds of mechanical parts. A procedure for the iron-based powder metallurgy is such that, first, a mixed powder is prepared by mixing an iron-based powder with a powder for alloy such as a copper (Cu) powder or a nickel (Ni) powder, a graphite powder, and a lubricant. Next, this mixed powder is put into a mold to perform press-molding, and the resultant is sintered to prepare a sintered body. Finally, this sintered body is subjected to cutting such as drilling process or turning on a lathe, so as to be prepared into a mechanical part having a desired shape.

[0003] An ideal for powder metallurgy is such that the sintered body is processed to be made usable as a mechanical part without performing cutting on the sintered body. However, the aforesaid sintering may generate non-uniform contraction of the raw material powder. In recent years, the dimension precision required in the mechanical parts is increasing, and the shapes of the parts are becoming more complex. For this reason, it is becoming essential to perform cutting on the sintered body. From such a background, machinability is imparted to the sintered body so that the sintered body can be smoothly processed.

[0004] There is a technique of adding a manganese sulfide (MnS) powder to the mixed powder as means for imparting the machinability. Addition of the MnS powder is effective for cutting at a comparatively low speed, such as drilling. However, addition of a manganese sulfide powder is not necessarily effective for cutting at a high speed that is performed in recent years, and raises problems such as generation of contamination on the sintered body and decrease in the mechanical strength.

[0005] For this reason, additives disclosed, for example, in Patent Literatures 1 to 4 are proposed as techniques other than the addition of manganese sulfide.

[0006] Patent Literature 1 (Japanese Examined Patent Application Publication No. S52-16684) discloses a sintered steel in which 0.1 to 1.0% of calcium sulfide, 0.1 to 2% of carbon (C), and 0.5 to 5.0% of copper (Cu) are incorporated into an iron-based raw material powder obtained by allowing a needed amount of carbon and copper to be contained in an iron powder.

[0007] Patent Literature 2 (Japanese Unexamined Patent Application Publication No. 2008-502807 derived from International Patent Application) discloses a metallurgy powder composition comprising a powder containing calcium aluminate. The powder containing calcium aluminate contains 51 to 57 wt% of alumina, 31 to 37 wt% of calcium oxide, less than 6.0 wt% of SiO_2, less than 2.5 wt% of Fe_2O_3, less than 3.0 wt% of TiO_2, less than 2.0 wt% of MgO, less than 0.2 wt% of K_2O, and less than 0.2 wt% of sulfur.

[0008] Patent Literature 3 (Japanese Unexamined Patent Application Publication No. 2010-236061) discloses an iron-based mixed powder containing an oxide powder of SiO_2-CaO-MgO at a ratio of 0.01 to 1.0 parts by mass relative to 100 parts by mass of an iron-based powder.

[0009] Patent Literature 4 (Japanese Unexamined Patent Application Publication No. H09-279204) discloses an iron-based mixed powder for powder metallurgy mainly made of iron powder and containing 0.02 to 0.3 wt% of a CaO-Al_2O_3-SiO_2 composite oxide powder having an average particle size of 50 μm or less.

[0010] Incorporation of calcium sulfide into an iron-based raw material powder disclosed in Patent Literature 1 raises problems such as considerable decrease in the strength of the mechanical parts and unstable product quality caused by change with lapse of time of the mixed powder. Further, when the sintered steel disclosed in Patent Literature 1 is processed with use of a cutting tool, the chips are hardly fragmented finely. From this, the sintered steel disclosed in Patent Literature 1 can hardly be said to be excellent to such a level as to satisfy the current demand for the chip controllability.

[0011] According to the technique disclosed in Patent Literature 2, the metallurgy powder composition contains an insufficient amount of Al_2O_3 and an excessive amount of CaO relative to a theoretical ratio of monocalcium aluminate which is CaO : Al_2O_3 = 35.5 : 64.5. This excessive amount of CaO reacts with other oxides or sulfur or is singly present, whereby the characteristics of the sintered body are hardly stabilized.

[0012] According to the technique disclosed in Patent Literatures 3 and 4, ceramic powders exposed on the machined surface at the time of cutting adhere onto the tool surface to form a tool protection film. This tool protection film prevents deterioration in the material quality of the tool and improves the cutting property. However, a further improvement of machinability immediately after the start of cutting (at an initial stage of cutting) is desired on a sintered body prepared with use of an iron-based mixed powder disclosed in Patent Literatures 3 and 4.

[0013] The present invention has been made in view of the aforementioned current circumstances, and an object thereof is to provide a mixed powder for iron-based powder metallurgy capable of preparing a sintered body that is excellent in machinability both at an initial stage of starting the cutting and in a long period of time of cutting.

Citation List

Patent Literature

[0014]

Patent Literature 1: Japanese Examined Patent Application Publication No. S52-16684
Patent Literature 2: Japanese Unexamined Patent Application Publication No. 2008-502807 derived from International Patent Application
Patent Literature 3: Japanese Unexamined Patent Application Publication No. 2010-236061
Patent Literature 4: Japanese Unexamined Patent Application Publication No. H09-279204

Summary of Invention

[0015] A mixed powder for iron-based powder metallurgy of the present invention comprises at least one ternary oxide selected from the group consisting of Ca-Al-Si oxides and Ca-Mg-Si oxides, and at least one binary oxide selected from the group consisting of Ca-Al oxides and Ca-Si oxides, wherein the ternary oxide and the binary oxide are contained in a sum weight of 0.025 wt% or more to 0.3 wt% or less.

[0016] The present invention is also directed to a sintered body prepared by sintering the mixed powder for iron-based powder metallurgy described above.

Description of Embodiments

[0017] In order to achieve the aforementioned object, the present inventor has confirmed a mechanism of reaction between the oxide ($2CaO{\bullet}Al_2O_3{\bullet}SiO_2$ powder) contained in the sintered body and the titanium oxide (TiO_2) powder contained in a cutting tool or in the coating of a cutting tool. Specifically, a mixed powder of $2CaO{\bullet}Al_2O_3{\bullet}SiO_2$ powder and TiO_2 powder was heated in ambient air under no pressure applied, and the reaction product thereof was analyzed by X-ray diffraction.

[0018] As a result, the following has been made clear. When the mixed powder is heated at 700°C for 5 minutes, TiO_2 does not react with $2CaO{\bullet}Al_2O_3{\bullet}SiO_2$; however, when the mixed powder is heated at 700°C for one hour, $2CaO{\bullet}Al_2O_3{\bullet}SiO_2$ is decomposed into various oxides such as $CaO{\bullet}Al_2O_3{\bullet}2SiO_2$ and $2CaO{\bullet}SiO_2$, and further $CaO{\bullet}TiO_2$ is also generated.

[0019] Based on the above analysis result, the present inventor has assumed that, in a state of immediately after the start of cutting in which the edge temperature of the cutting tool is low, the reaction between a ternary oxide and TiO_2 in the tool does not occur sufficiently, and a protection coating film is hardly formed. Also, the present inventor has confirmed that, in a state in which a predetermined period of time has passed from the start of cutting and the edge temperature of the cutting tool is high, Ca in the ternary oxide reacts with TiO_2 on the tool surface to form a protection coating film on the tool surface, and also various binary oxides are formed. The present inventor has assumed that, in cutting for a long period of time, the ternary oxide exhibits an effect of suppressing tool wear more than the binary oxide because Ca in the binary oxide reacts with TiO_2 on the surface of the cutting tool to be lost, and hard Al_2O_3, SiO_2 are generated to provoke tool wear.

[0020] Based on the above assumption, the present inventor has found out that the machinability at an initial stage of cutting is enhanced by the binary oxide, and machinability in cutting for a long period of time is enhanced by the ternary oxide that hardly generate hard Al_2O_3, SiO_2, thereby completing the present invention shown below.

[0021] According to the present invention, there can be provided a mixed powder for iron-based powder metallurgy capable of preparing a sintered body that is excellent in machinability both at an initial stage of starting the cutting and in a long period of time of cutting.

[0022] Hereafter, a mixed powder for iron-based powder metallurgy according to the present invention and a method for producing the same will be specifically described.

<Mixed powder for iron-based powder metallurgy>

[0023] A mixed powder for iron-based powder metallurgy of the present invention is preferably formed by mixing an iron-based powder with a ternary oxide and a binary oxide. Various kinds of additives such as powders for alloy, graphite powders, lubricants, binders, and machinability improvers may be appropriately added into this mixed powder. In addition to these, the mixed powder may contain a slight amount of inevitable impurities during the process of producing the mixed powder for iron-based powder metallurgy. The mixed powder for iron-based powder metallurgy of the present invention may be put into a mold or the like to be molded and thereafter sintered to give a sintered body. The sintered body thus prepared may be subjected to cutting process, so as to be made usable in various kinds of mechanical parts. The use and the production method of this sintered body will be described later.

<Iron-based powder>

[0024] The iron-based powder is a main constituent component constituting the mixed powder for iron-based powder metallurgy, and is preferably contained at a weight ratio of 60 wt% or more relative to the total amount of the mixed powder for iron-based powder metallurgy. Here, wt% of the iron-based powder as used herein refers to the occupied ratio relative to the total weight of the constituent components of the mixed powder for iron-based powder metallurgy other than the lubricants. Hereafter, it is assumed that, when wt% of each component is defined, the definition refers to the occupied weight ratio relative to the total weight of the constituent components of the mixed powder for iron-based powder metallurgy other than the lubricants.

[0025] The above iron-based powder usable in the present invention may be, for example, a pure iron powder such as an atomized iron powder or a reduced iron powder, a partially diffused alloyed steel powder, a completely alloyed steel powder, a hybrid steel powder obtained by partially diffusing alloy components into a completely alloyed steel powder, or the like. A volume-average particle size of the iron-based powder is preferably 50 μm or more, more preferably 70 μm or more. When the volume-average particle size of the iron-based powder is 50 μm or more, the handling property is excellent. Further, the volume-average particle size of the iron-based powder is preferably 200 μm or less, more preferably 100 μm or less. When the volume-average particle size of the iron-based powder is 200 μm or less, a precision shape can be readily molded, and also a sufficient strength can be obtained.

<Binary oxide and ternary oxide>

[0026] The mixed powder for iron-based powder metallurgy of the present invention contains both of a binary oxide and a ternary oxide in a sum weight of 0.025 wt% or more to 0.3 wt% or less. The binary oxide can improve the machinability at an initial stage of cutting when the sintered body is used in a cutting process. The ternary oxide can improve the machinability when cutting is performed for a long period of time. When these two kinds of oxides are contained at such a weight ratio, a sintered body having an excellent machinability both at an initial stage of cutting and in cutting for a long period of time can be prepared.

[0027] The sum weight of the oxides is preferably 0.03 wt% or more, more preferably 0.04 wt% or more, still more preferably 0.05 wt% or more, and particularly preferably 0.1 wt% or more. In view of costs, the weight ratio of the binary oxide and ternary oxide is preferably as small as possible. Further, the sum weight of the oxides is preferably 0.25 wt% or less, more preferably 0.2 wt% or less. When the sum weight of the oxides is 0.25 wt% or less, the radial crushing strength of the sintered body can be sufficiently ensured.

[0028] The binary oxide means a composite oxide of two types of elements, and the ternary oxide means a composite oxide of three types of elements. Specifically, the binary oxide is preferably a composite oxide of two types of elements selected from the group consisting of Ca, Mg, Al, Si, Co, Ni, Ti, Mn, Fe, and Zn, and is more preferably a Ca-Al oxide, a Ca-Si oxide, or the like. The Ca-Al oxide may be, for example, $CaO \cdot Al_2O_3$, $12CaO \cdot 7Al_2O_3$, or the like. The Ca-Si oxide may be, for example, $2CaO \cdot SiO_2$ or the like.

[0029] The ternary oxide to be used is preferably a composite oxide of three types of elements selected from the group consisting of Ca, Mg, Al, Si, Co, Ni, Ti, Mn, Fe, and Zn, and is more preferably a Ca-Al-Si oxide, a Ca-Mg-Si oxide, or the like. The Ca-Al-Si oxide may be, for example, $2CaO \cdot Al_2O_3 \cdot SiO_2$ or the like. The Ca-Mg-Si oxide may be, for example, $2CaO \cdot MgO \cdot 2SiO_2$ or the like. Among these, it is preferable to add $2CaO \cdot Al_2O_3 \cdot SiO_2$. The aforementioned $2CaO \cdot Al_2O_3 \cdot SiO_2$ reacts with TiO_2 contained in the cutting tool or in the coating formed on the cutting tool to form a protection coating film on the surface of the cutting tool, whereby the machinability can be considerably improved.

[0030] A shape of the binary oxide and the ternary oxide is not particularly limited; however, the binary oxide and the ternary oxide preferably have a spherical shape or a crushed spherical shape, that is, a shape that is round as a whole.

[0031] The volume-average particle size of the binary oxide and the ternary oxide is preferably 0.1 μm or more, more preferably 0.5 μm or more, and still more preferably 1 μm or more. There is a tendency such that, according as the volume-average particle size is smaller, the machinability of the sintered body can be improved by a smaller amount of addition. Further, the volume-average particle size of the binary oxide and the ternary oxide is preferably 15 μm or less, more preferably 10 μm or less, and still more preferably 9 μm or less. When the volume-average particle size is too large, it is difficult to improve the machinability of the sintered body. The above volume-average particle size is a value of the particle size D_{50} at an accumulated value of 50% in the particle size distribution obtained by using a laser diffraction particle size distribution measurement device (Microtrac "MODEL9320-X100" manufactured by Nikkiso Co., Ltd.). By using the binary oxide and the ternary oxide in combination as in the present invention, the amount of addition of the two types of oxides can be reduced, thereby also leading to reduction of the raw material costs.

[0032] The content of the binary oxide is preferably 0.01 wt% or more, more preferably 0.03 wt% or more, and still more preferably 0.05 wt% or more. Further, the content of the binary oxide is preferably 0.25 wt% or less, more preferably 0.2 wt% or less, and still more preferably 0.15 wt% or less. When the binary oxide is contained at such a weight ratio, it is possible to obtain a sintered body having an excellent machinability at an initial stage of cutting while suppressing the costs.

[0033] The content of the ternary oxide is preferably 0.01 wt% or more, more preferably 0.03 wt% or more, and still more preferably 0.05 wt% or more. Further, the content of the ternary oxide is preferably 0.25 wt% or less, more preferably 0.2 wt% or less, and still more preferably 0.15 wt% or less. When the ternary oxide is contained at such a weight ratio, it is possible to obtain a sintered body having an excellent machinability even in cutting for a long period of time while suppressing the costs.

[0034] The weight ratio of the ternary oxide and the binary oxide is preferably 9 : 1 to 1 : 9, more preferably 9 : 1 to 3 : 7, and still more preferably 7 : 3 to 4 : 6. When these two kinds of oxides are contained at such a weight ratio, a sintered body that can be easily machined both at an initial stage of cutting and in cutting for a long period of time can be prepared.

<Powder for alloy>

[0035] A powder for alloy is added for the purpose of promoting bonding between the iron-based powders and enhancing the strength of the sintered body after the sintering. Such a powder for alloy is contained preferably at a ratio of 0.1 wt% or more to 10 wt% or less relative to the whole of the mixed powder for iron-based powder metallurgy. When the ratio is 0.1 wt% or more, the strength of the sintered body can be enhanced. When the ratio is 10 wt% or less, the dimension precision of the sintered body at the time of sintering can be ensured.

[0036] The powder for alloy may be, for example, a non-ferrous metal power such as copper (Cu) powder, nickel (Ni) powder, Mo powder, Cr powder, V powder, Si powder, or Mn powder, a copper suboxide powder, or the like. These may be used either alone as one kind or in combination of two or more kinds.

<Lubricant>

[0037] A lubricant is added so that the molded body obtained by compressing the mixed powder for iron-based powder metallurgy in a mold can be readily taken out from the mold. In other words, when a lubricant is added into the mixed powder for iron-based powder metallurgy, the withdrawing pressure at the time of taking the molded body out from the mold can be reduced, so that cracking of the molded body and damage of the mold can be prevented. The lubricant may be added into the mixed powder for iron-based powder metallurgy or may be applied onto the surface of the mold. When the lubricant is added into the mixed powder for iron-based powder metallurgy, the lubricant is contained preferably at a ratio of 0.01 wt% or more, more preferably at a ratio of 0.1 wt% or more, relative to the weight of the mixed powder for iron-based powder metallurgy. When the content of the lubricant is 0.01 wt% or more, the effect of reducing the withdrawing pressure of the sintered body can be readily obtained. Further, the lubricant is contained preferably at a ratio of 1.5 wt% or less, more preferably at a ratio of 1.2 wt% or less, relative to the weight of the mixed powder for iron-based powder metallurgy. When the content of the lubricant is 1.5 wt% or less, a sintered body having a high density can be readily obtained, and a sintered body having a high strength can be obtained.

[0038] The lubricant that can be put to use may be one or more selected from the group consisting of metal soap (lithium stearate, calcium stearate, zinc stearate, or the like), stearamide, fatty acid amide, amide wax, hydrocarbon-based wax, and cross-linked alkyl (meth)acrylate resin. Among these, it is preferable to use an amide-based lubricant from the viewpoint of having a good performance of allowing the powder for alloy, graphite powder, or the like to adhere onto the iron-based powder surface and being capable of readily reducing the segregation of the iron-based mixed powder.

<Binder>

[0039] A binder is added for the purpose of allowing the powder for alloy and the graphite powder to adhere onto the iron-based powder surface. The binder that is put to use may be a butene-based polymer, a methacrylate-based polymer, or the like. As the butene-based polymer, it is preferable to use a 1-butene homopolymer made of butene alone or a copolymer of butene and alkene. The alkene herein referred to is preferably a lower alkene, and is preferably ethylene or propylene. As the methacrylate-based polymer, it is possible to use at least one selected from the group consisting of methyl methacrylate, ethyl methacrylate, butyl methacrylate, cyclohexyl methacrylate, ethylhexyl methacrylate, lauryl methacrylate, methyl acrylate, and ethyl acrylate.

[0040] The binder is contained preferably at a ratio of 0.01 wt% or more, more preferably at a ratio of 0.05 wt% or more, and still more preferably at a ratio of 0.1 wt% or more, relative to the weight of the mixed powder for iron-based powder metallurgy. The binder is contained preferably at a ratio of 0.5 wt% or less, more preferably at a ratio of 0.4 wt% or less, and still more preferably at a ratio of 0.3 wt% or less, relative to the weight of the mixed powder for iron-based powder metallurgy.

<Machinability improver>

[0041] The machinability improver is added for the purpose of improving the machinability of the sintered body obtained by sintering the mixed powder for iron-based powder metallurgy. The machinability improver to be used is preferably calcium sulfide. When calcium sulfide is used as the machinability improver, it is preferable that the surface of the powder made of calcium sulfide is coated, or alternatively, the powder of calcium sulfide is heated to 300°C to 900°C in advance to change the powder into a form of II type calcium sulfate, because calcium sulfide has moisture absorptivity and may deteriorate the stability of performance. This can suppress the moisture absorptivity of the powder made of calcium sulfide and can stabilize the performance of the sintered body. Further, since II type calcium sulfate has considerably low moisture absorptivity, the performance of the sintered body can be stabilized. For coating of the powder made of calcium sulfide, an organic material such as an amide-based polymer material or styrene•butadiene rubber can be used.

[0042] The machinability improver is contained preferably at a ratio of 0.01 wt% or more, more preferably at a ratio of 0.05 wt% or more, and still more preferably at a ratio of 0.1 wt% or more, relative to the weight of the mixed powder for iron-based powder metallurgy. The machinability improver is contained preferably at a ratio of 1 wt% or less, more preferably at a ratio of 0.4 wt% or less, and still more preferably at a ratio of 0.3 wt% or less, relative to the weight of the mixed powder for iron-based powder metallurgy.

<Method for producing mixed powder for iron-based powder metallurgy>

[0043] The mixed powder for iron-based powder metallurgy of the present invention can be prepared by mixing the iron-based powder with the ternary oxide and the binary oxide with use of, for example, a mechanical agitation mixer. In addition to these powders, various kinds of additives such as a powder for alloy, a graphite powder, a lubricant, and a binder may be suitably added. The mechanical agitation mixer may be, for example, a high-speed mixer, a Nauta Mixer, a V-type mixer, a double-cone blender, or the like. The order of mixing these powders is not particularly limited. The mixing temperature is not particularly limited; however, the mixing temperature is preferably 150°C or lower in view of suppressing oxidation of the iron-based powder in the mixing step.

<Method for producing sintered body>

[0044] After the mixed powder for iron-based powder metallurgy prepared in the above is put into a mold, a pressure of 300 MPa or higher to 1200 MPa or lower may be applied to produce a pressed-powder molded body. The molding temperature during this time is preferably 25°C or higher to 150°C or lower.

[0045] Then, the pressed-powder molded body prepared in the above is sintered by an ordinary sintering method to obtain a sintered body. The sintering conditions may be a non-oxidizing atmosphere or a reducing atmosphere. The above pressed-powder molded body is preferably sintered at a temperature of 1000°C or higher to 1300°C or lower for 5 minutes or more to 60 minutes or less in an atmosphere such as a nitrogen atmosphere, a mixed atmosphere of nitrogen and hydrogen, or a hydrocarbon atmosphere.

<Sintered body>

[0046] The sintered body thus prepared can be used as a mechanical part of an automobile, an agricultural instrument, a power tool, a home electrical appliance, or the like by being processed with various kinds of tools such as a cutting tool in accordance with the needs. Such a cutting tool may be, for example, a drill, an end mill, a cutting tool for milling, a cutting tool for turning on a lathe, a reamer, a tap, or the like.

[0047] According to the above-described embodiment, since the mixed powder for iron-based powder metallurgy contains a binary oxide, a sintered body having an excellent machinability at an initial stage of cutting can be obtained. Also, since the mixed powder for iron-based powder metallurgy contains a ternary oxide, a sintered body having an excellent machinability in cutting for a long period of time can be obtained. Further, since the sum weight of the binary oxide and the ternary oxide is within the above range, the machinability at an initial stage of cutting and the machinability in cutting for a long period of time are highly compatible with each other.

[0048] Since the mixed powder for iron-based powder metallurgy contains the ternary oxide and the binary oxide at a weight ratio of 9 : 1 to 1 : 9, a good balance is provided between the machinability at an initial stage of cutting and the machinability in cutting for a long period of time.

[0049] Since the mixed powder for iron-based powder metallurgy contains the ternary oxide and the binary oxide in a sum weight of 0.05 wt% or more to 0.2 wt% or less, a sintered body having an excellent balance between the machinability at an initial stage of cutting and the machinability in cutting for a long period of time can be prepared.

Examples

[0050] Hereafter, the present invention will be described in further detail by way of Examples; however, the present invention is not limited to these.

(Examples 1 to 6 and Comparative Examples 1 to 6)

[0051] In each Example and in each Comparative Example, a pure iron powder (trade name: ATOMEL 300M (manufactured by Kobe Steel, Ltd.)) was mixed with 2 wt% of copper powder (trade name: CuATW-250 (manufactured by Fukuda Metal Foil & Powder Co., Ltd.)), a binary oxide and/or a ternary oxide having a composition in wt% shown in the section of "binary oxide" and/or "ternary oxide" in Table 1, graphite powder (trade name: CPB (manufactured by Nippon Graphite Industries, Co., Ltd.)), and 0.75 wt% of zinc stearate, so as to prepare a mixed powder for iron-based powder metallurgy. The graphite powder was added at an amount such that the amount of carbon after the sintering would be 0.75 wt%. For both of the binary oxide and the ternary oxide, those having a volume-average particle size of 2 μm were used.

[0052] The above mixed powder for iron-based powder metallurgy was put into a mold, and a test piece was molded so as to have a ring shape with an outer diameter of 64 mm, an inner diameter of 24 mm, and a thickness of 20 mm and to have a molding density of 7.00 g/cm^3. Next, this test piece having a ring shape was sintered at 1130°C for 30 minutes in a 10 vol% H_2-N_2 atmosphere, so as to prepare a sintered body.

[0053] The sintered body thus prepared was turned on a lathe by using a cermet tip (ISO type number: SNGN120408 non-breaker) under conditions with a circumferential speed of 160 m/min, a cutting rate of 0.5 mm/pass, and a feed rate of 0.1 mm/rev, and with a dry type, so as to measure a tool wear amount of the cutting tool. For the tool wear amount, a wear amount (μm) of the cutting tool after the sintered body was cut for 330 m from the start of cutting and a wear amount (μm) of the cutting tool after the sintered body was cut for 1150 m from the start of cutting were measured with a tool microscope. The evaluation results of the wear amounts are shown in the section of "tool wear amount" in Table 1. The smaller the value of the wear amount is, the more excellent the machinability of the sintered body is.

[Table 1]

	Composition	Examples						Comparative Examples					
		1	2	3	4	5	6	1	2	3	4	5	6
Ternary oxide (wt%)	$2CaO \cdot MgO \cdot 2SiO_2$	0.05	0.05	0.05	-	-	-	-	-	0.1	-	-	-
	$2CaO \cdot Al_2O_3 \cdot SiO_2$	-	-	-	0.05	0.05	0.05	-	-	-	0.1	-	-
Binary oxide (wt%)	$CaO \cdot Al_2O_3$	0.05	-	-	0.05	-	-	-	0.1	-	-	-	-
	$2CaO \cdot SiO_2$	-	0.05	-	-	0.05	-	-	-	-	-	0.1	-
	$12CaO \cdot 7Al_2O_3$	-	-	0.05	-	-	0.05	-	-	-	-	-	0.1
Sintered body density (g/cm^3)		6.94	6.94	6.94	6.95	6.95	6.95	6.94	6.94	6.94	6.95	6.94	6.94
Radial crushing strength (MPa)		890	883	899	910	906	900	915	900	889	907	904	901
Tool wear amount (μm)	Cutting distance (330 m)	19.4	20.6	21.2	18.3	18.4	19.6	89.4	22.1	26.4	24.1	23.4	21.1
	Cutting distance (1150 m)	58.4	60.1	60.7	45.2	44.5	50.2	253.0	83.8	69.6	58.5	86.8	90.2

[0054] In Table 1, the sintered body density was a value as determined by making measurements in accordance with Japan Powder Metallurgy Association Standard (JPMA M 01). The radial crushing strength was a value as determined by making measurements in accordance with JIS Z 2507-2000. The higher the radial crushing strength is, the less likely the sintered body is broken, so that the sintered body has a higher strength.

[0055] Referring to Table 1, Examples 1 to 6 are each a sintered body containing a binary oxide and a ternary oxide in combination. Comparative Example 1 is a sintered body containing neither a binary oxide nor a ternary oxide. Comparative Examples 3 and 4 are each a sintered body containing a ternary oxide alone. Comparative Examples 2, 5 and 6 are each a sintered body containing a binary oxide alone. In Comparative Example 2, a component disclosed in Patent Literature 1 ($CaO•Al_2O_3$) is used. In Comparative Example 3, a component disclosed in Patent Literature 3 ($2CaO•MgO•2SiO_2$) is used. In Comparative Example 4, a component disclosed in Patent Literature 4 ($2CaO•Al_2O_3•SiO_2$) is used.

[0056] With respect to the sintered bodies of Examples 1 to 6, it has been made clear that the tool wear amount can be considerably reduced both in cutting for 330 m (initial wear) and in cutting for 1150 m (long-time wear), as compared with those of Comparative Examples 1 to 6. The reason therefor probably seems to be that the binary oxide improves the machinability at an initial stage of cutting and the ternary oxide improves the machinability in cutting for a long period of time, so that these effects are combined to enhance the machinability of the sintered body both at an initial stage of cutting and in cutting for a long period of time.

[0057] When Comparative Example 1 is compared with Comparative Examples 2, 5, and 6, it will be understood that the addition of a binary oxide produces an effect of suppressing the initial wear of the cutting tool. Further, when Comparative Example 1 is compared with Comparative Examples 3 and 4, it will be understood that the addition of a ternary oxide produces an effect of suppressing the wear of the cutting tool in cutting for a long period of time.

[0058] From the results of the Examples and the Comparative Examples shown in Table 1, it has been made clear that, when the binary oxide and the ternary oxide are contained in a sum weight of 0.1 wt%, a sintered body that can be easily machined both at an initial stage of cutting and in cutting for a long period of time can be obtained, thereby showing the effect of the present invention.

(Examples 7 to 18)

[0059] In Examples 7 to 18, a mixed powder for iron-based powder metallurgy and a sintered body were prepared in the same manner as in Example 1 except that the sum weight of the binary oxide and the ternary oxide was fixed to 0.1 wt% and that the weight ratio and the composition thereof were changed to the composition and wt% shown in the sections of "binary oxide" and "ternary oxide" in Table 2. On the sintered body thus prepared, evaluation of the tool wear amount was made by the same method as in Example 1. The results of these are shown in the following Table 2.

[Table 2]

	Composition	Examples											
		7	8	9	10	11	12	13	14	15	16	17	18
Ternary oxide (wt%)	$2CaO \cdot MgO \cdot 2SiO_2$	-	-	-	-	-	-	-	-	-	-	-	-
	$2CaO \cdot Al_2O_3 \cdot SiO_2$	0.09	0.08	0.03	0.01	0.09	0.08	0.03	0.01	0.09	0.08	0.03	0.01
Binary oxide (wt%)	$CaO \cdot Al_2O_3$	0.01	0.02	0.07	0.09	-	-	-	-	-	-	-	-
	$2CaO \cdot SiO_2$	-	-	-	-	0.01	0.02	0.07	0.09	-	-	-	-
	$12CaO \cdot 7Al_2O_3$	-	-	-	-	-	-	-	-	0.01	0.02	0.07	0.09
Tool wear amount (μm)	Cutting distance (330 m)	20.4	20.1	19.6	23.2	20.3	18.7	18.4	23.8	23.6	22.5	21.3	23.0
	Cutting distance (1150 m)	54.3	48.3	54.5	80.9	50.1	43.3	52.1	78.8	52.3	48.8	53.6	87.4

[0060] From the results shown in Table 2, it has been made clear that, when the ternary oxide and the binary oxide are contained at a weight ratio of 9 : 1 to 1 : 9, the machinability at an initial stage of cutting and the machinability in cutting for a long period of time are compatible with each other. In particular, when the weight ratio is 9 : 1 to 3 : 7, the machinability at an initial stage of cutting and the machinability in cutting for a long period of time are highly compatible with each other.

(Examples 19 to 21 and Comparative Examples 7 to 9)

[0061] In Examples 19 to 21 and Comparative Examples 7 to 9, a mixed powder for iron-based powder metallurgy and a sintered body were prepared in the same manner as in Example 1 except that the weights of the binary oxide and the ternary oxide were changed to the composition and wt% shown in the sections of "binary oxide" and "ternary oxide" in Table 3. On the sintered body thus prepared, evaluation of the wear amount was made by the same method as in Example 1. The results of these are shown in the following Table 3.

[Table 3]

	Composition	Examples			Comparative Examples		
		19	20	21	7	8	9
Ternary oxide (wt%)	$2CaO\cdot Al_2O_3\cdot SiO_2$	0.025	0.10	0.15	0.005	0.01	0.20
Binary oxide (wt%)	$CaO\cdot Al_2O_3$	0.025	0.10	0.15	0.005	0.01	0.20
Sum content of oxides (wt%)		0.05	0.20	0.3	0.01	0.02	0.40
Radial crushing strength (MPa)		913	840	802	916	915	720
Tool wear amount (μm)	Cutting distance (330 m)	20.2	16.1	15.4	26.7	25.3	14.4
	Cutting distance (1150 m)	56.4	40.4	37.9	204	103.3	36.6

[0062] From the results shown in Table 3, it has been made clear that, when a sum content of the binary oxide and the ternary oxide is 0.025 wt% or more to 0.3 wt% or less, the machinability at an initial stage of cutting and the machinability in cutting for a long period of time are compatible with each other, thereby showing the effect of the present invention. On the other hand, it has been made clear that, when a sum weight% of the binary oxide and the ternary oxide is less than 0.025 wt% (Comparative Examples 7 and 8), the effect of improving the machinability cannot be sufficiently obtained, and that, when a sum weight of the binary oxide and the ternary oxide exceeds 0.3 wt% (Comparative Example 9), the radial crushing strength is lower than 800 MPa, thereby giving an insufficient strength of the sintered body.

Claims

1. A mixed powder for iron-based powder metallurgy, comprising at least one ternary oxide selected from the group consisting of Ca-Al-Si oxides and Ca-Mg-Si oxides, and at least one binary oxide selected from the group consisting of Ca-Al oxides and Ca-Si oxides, wherein the ternary oxide and the binary oxide are contained in a sum weight of 0.025 wt% or more to 0.3 wt% or less.

2. The mixed powder for iron-based powder metallurgy according to claim 1, wherein the ternary oxide and the binary oxide are contained at a weight ratio of 9 : 1 to 1 : 9.

3. The mixed powder for iron-based powder metallurgy according to claim 1 or 2, wherein the ternary oxide and the binary oxide are contained in a sum weight of 0.05 wt% or more to 0.2 wt% or less.

4. The mixed powder for iron-based powder metallurgy according to claim 1, wherein the binary oxide is at least one selected from the group consisting of $CaO\cdot Al_2O_3$, $2CaO\cdot SiO_2$, and $12CaO\cdot 7Al_2O_3$.

5. The mixed powder for iron-based powder metallurgy according to claim 1, wherein the ternary oxide is at least one selected from the group consisting of $2CaO\cdot MgO\cdot 2SiO_2$ and $2CaO\cdot Al_2O_3\cdot SiO_2$.

6. A sintered body prepared by sintering the mixed powder for iron-based powder metallurgy according to claim 1.

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
B22F1/00(2006.01)i, *C22C33/02*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22F1/00, C22C33/02

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

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Kokai Jitsuyo Shinan Koho	1971-2016	Toroku Jitsuyo Shinan Koho	1994-2016

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2012-513538 A (Hoganas AB (publ)), 14 June 2012 (14.06.2012), paragraphs [0001] to [0091]; fig. 1 to 2 & US 2011/0262294 A1 paragraphs [0001] to [0095]; fig. 1 to 2 & WO 2010/074627 A1 & EP 2384250 A1 & CA 2748028 A1 & TW 201031480 A & KR 10-2011-0099752 A & CN 102325614 A & RU 2011130568 A	1-6
A	JP 8-260113 A (Toyota Motor Corp.), 08 October 1996 (08.10.1996), entire text & US 5679909 A whole document & EP 733718 A1	1-6

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/063170

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2010-236061 A (JFE Steel Corp.), 21 October 2010 (21.10.2010), entire text (Family: none)	1-6
A	JP 2008-502807 A (Hoeganaes Corp.), 31 January 2008 (31.01.2008), paragraphs [0001] to [0074] & US 2005/0274223 A1 paragraphs [0001] to [0074] & WO 2005/123973 A1 & EP 1761653 A1	1-6
A	JP 1-255604 A (Kawasaki Steel Corp.), 12 October 1989 (12.10.1989), entire text (Family: none)	1-6
P,A	JP 2015-172238 A (JFE Steel Corp.), 01 October 2015 (01.10.2015), entire text (Family: none)	1-6

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- JP 2008502807 A **[0007] [0014]**
- JP 2010236061 A **[0008] [0014]**
- JP H09279204 B **[0009] [0014]**