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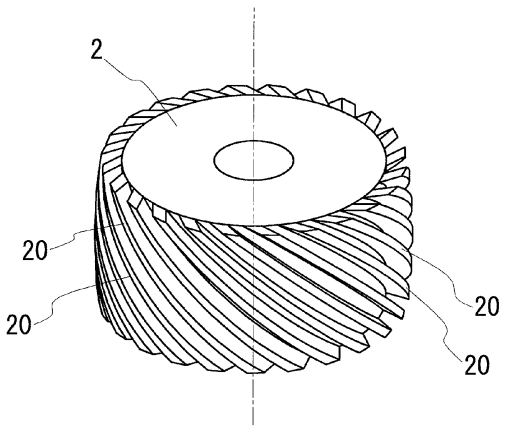
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(54) METHOD FOR MANUFACTURING SINTERED COMPACT, AND SINTERED COMPACT

(57) A sintered body manufacturing method includes: a preparation step of preparing a raw material powder containing an iron-based metal powder; a molding step of subjecting the raw material powder to uniaxial pressing using a die to produce a green compact having an overall average relative density of 93% or more; a machining step of machining the green compact to produce a machined compact; and a sintering step of sintering the machined compact to obtain a sintered body.

FIG. 3



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Description

Technical Field

[0001] The present invention relates to a method for manufacturing a sintered body and to a sintered body.

[0002] The present application claims priority from Japanese Patent Application No. 2016-077069 filed on April 7, 2016, the entire contents of which are incorporated herein by reference.

Background Art

[0003] PTL 1 discloses a metallic member manufacturing method (a sintered body manufacturing method) comprising: calcining a compact prepared by pressure molding of a metal powder; machining the calcined compact; and then subjecting the machined compact to main firing. In the manufacturing method in PTL 1, the calcined compact prepared by calcining the compact has higher mechanical strength than the uncalcined compact, is less likely to chip during machining, and is therefore easily machined. The calcined compact has a lower hardness than the sintered body subjected to the main firing and is therefore easily machined. Specifically, in the manufacturing method in PTL 1, the green compact is calcined to increase its mechanical strength, and then the calcined compact is machined, so that chipping and cracking are less likely to occur during the machining.

Citation List

Patent Literature

[0004] PTL 1: Japanese Unexamined Patent Application Publication No. 2007-77468

Summary of Invention

[0005] The sintered body manufacturing method of the present disclosure comprises:

a preparation step of preparing a raw material powder containing an iron-based metal powder;
a molding step of subjecting the raw material powder to uniaxial pressing using a die to produce a green compact having an overall average relative density of 93% or more;
a machining step of machining the green compact to produce a machined compact; and
a sintering step of sintering the machined compact to obtain a sintered body.

[0006] The sintered body of the present disclosure is an iron-based sintered body having an overall average relative density of 93% or more.

Brief Description of Drawings

[0007]

[Fig. 1] Figure 1 shows schematic illustrations of machining with a cutting tool, an upper illustration showing how a green compact is machined with the cutting tool, a lower illustration showing how a solidified metal body is machined with the cutting tool.
[Fig. 2] Figure 2 is a schematic perspective view of an assembly described in a production example and including a planetary carrier and planetary gears.
[Fig. 3] Figure 3 is a schematic side view of a planetary gear described in the production example.
[Fig. 4] Figure 4 shows the planetary carrier described in the production example, an upper illustration being a schematic front view, a lower illustration being an A-Across section of the upper illustration.

Description of Embodiments

[Problems to be Solved by the Disclosure]

[0008] In the metal member manufacturing method in PTL 1, since the green compact is calcined, particles of the metal powder are sintered to some extent. Although the hardness of the calcined compact is lower than the hardness of the sintered body subjected to the main firing, the calcined compact has a certain hardness. Therefore, the technique in PTL 1 is susceptible to improvement in machinability. Moreover, since the particles of the metal powder are sintered during the calcination, machining chips must be melted in order to reuse the machining chips.

[0009] In the metal member manufacturing method in PTL 1, pressure molding, calcination, machining, and main firing are performed sequentially, and the number of steps for obtaining the metal member is large. Therefore, the technique in PTL 1 is susceptible to improvement in metal member productivity.

[0010] One object of the present disclosure is to provide a high-productivity sintered body manufacturing method in which an unsintered green compact can be easily machined.

[Advantageous Effects of the Disclosure]

[0011] In the sintered body manufacturing method of the present disclosure, the unsintered green compact can be easily machined, and therefore the sintered body of the present disclosure can be manufactured with high productivity.

Description of Embodiments of the Present Invention

[0012]

<1> A sintered body manufacturing method accord-

ing to an embodiment comprises:

a preparation step of preparing a raw material powder containing an iron-based metal powder;
a molding step of subjecting the raw material powder to uniaxial pressing using a die to produce a green compact having an overall average relative density of 93% or more;
a machining step of machining the green compact to produce a machined compact; and
a sintering step of sintering the machined compact to obtain a sintered body.

[0013] In the above sintered body manufacturing method, the green compact is produced by uniaxial pressing using the die. In the uniaxial pressing, the raw material powder can be molded under application of very high contact pressure. Therefore, a green compact having a high and uniform relative density with no brittle portions present locally can be easily obtained. The green compact obtained by uniaxial pressing is excellent in mechanical strength, and chipping and cracking are less likely to occur during machining. Specifically, since the green compact obtained by uniaxial pressing can be subjected to the machining step without calcination, the sintered body manufacturing method can produce the sintered body with high productivity.

[0014] In the above sintered body manufacturing method, the green compact produced has a uniform relative density of 93% or more. Therefore, when the machined compact prepared by machining the green compact is sintered, the change in the dimensions of the machined compact is stabilized. Specifically, the degree of contraction of the machined compact does not vary locally, and the entire machined compact contracts substantially uniformly. This can prevent the actual dimensions of the sintered body from deviating largely from the design dimensions. Preferably, the relative density is 95% or more.

[0015] In the above sintered body manufacturing method, since the green compact is subjected to the machining step without sintering, machining resistance during the machining step is low. Therefore, the speed of machining can be about 5 to about 10 times faster than that when a solidified metal body is machined, and the life of tools used for the machining can be about 10 to about 100 times longer. Since the machining resistance of the green compact is low, the stiffness of cutting tools and shanks can be low, and long or small-diameter cutting tools and shanks can be used for machining. Since flexibility in selection of cutting tools and shanks is high as described above, fewer constraints are imposed on the design of the shape of the sintered body, i.e., its design flexibility is high. For example, a finely machined sintered body such as a hollowed sintered body can be produced.

[0016] In the above sintered body manufacturing method, the machining chips generated during the machining can be reused without melting the chips. This is because, since the green compact is produced by cold pressure molding and is not sintered before machining, the metal powder contained in the machining chips is not altered.

[0017]

<2> In one mode of the sintered body manufacturing method according to the embodiment, the green compact is machined into a helical gear shape in the machining step.

[0018] In the sintered body manufacturing method according to the embodiment, since the green compact is machined before it is sintered, the green compact can be easily machined into a complex helical gear shape.

[0019]

<3> In another mode of the sintered body manufacturing method according to the embodiment, the uniaxial pressing is performed at a pressure of 600 MPa or higher.

[0020] When the green compact is produced in the above pressure range, the green compact obtained can have a high density and excellent machinability.

<4> In another mode of the sintered body manufacturing method according to the embodiment, the machining step is performed using a cutting method.

[0021] The cutting may be performed using at least one working tool such as a milling cutter, a hob, a broach, or a pinion cutter. Since the green compact is excellent in machinability, the cutting can be easily performed with high precision using any of the above working tools.

<5> In another mode of the sintered body manufacturing method according to the embodiment, the machining step is performed while compressive stress is applied to the green compact in such a direction that tensile stress acting on the green compact from a working tool is counteracted.

[0022] When the machining is performed while the compressive stress is applied to the green compact in such a direction that the tensile stress acting on the green compact is counteracted, the occurrence of chipping and cracking in the green compact can be effectively prevented. Means for applying the compressive stress will be exemplified in an embodiment described later.

<6> A sintered body according to another embodiment,
the sintered body composed of an iron-based material comprising:

an average relative density of the whole sintered body being 93% or more.

[0023] The sintered body in this embodiment has an average relative density of 93% or more and is a novel innovative sintered body. Since the average relative density of the sintered body in the embodiment is 93% or more, its mechanical strength compares favorably with that of a machined product prepared from a solidified metal body. The sintered body in this embodiment is manufactured by the sintered body manufacturing method in the preceding embodiment. Therefore, the sintered body can be manufactured with higher productivity than a machined product prepared from a solidified metal body. Preferably, the average relative density is 95% or more.

<7> In one mode of the sintered body according to this embodiment, the sintered body is a helical gear.

[0024] The sintered helical gear can be used as, for example, a component of a transmission of an automobile. As described above, the sintered body according to the embodiment has a mechanical strength that compares favorably with that of a machined product prepared from a solidified metal body. Therefore, the sintered body sufficiently functions as a component of an automobile to which a high load is applied.

<8> In one mode of the sintered body according to the embodiment that has the helical gear shape, the helical gear has teeth inclined 30° or more with respect to an axial line of the helical gear.

[0025] Since the above helical gear has excellent mechanical strength, the teeth of the helical gear are less likely to be damaged during use even when the teeth are inclined 30° or more with respect to the axial line. As the angle of the teeth with respect to the axial line increases, the noise generated when the helical gear is engaged with another gear is further reduced. Preferably, the angle of the teeth with respect to the axial line is 50° or more.

Details of Embodiments of the Present Invention

[0026] A specific example of a sintered body manufacturing method according to an embodiment of the present invention will be described with reference to the drawings. However, the present invention is not limited to this example. The present invention is defined by the scope of the claims and is intended to include any modifications within the scope and meaning equivalent to the scope of the claims.

<Embodiment 1>

<<Summary of sintered body manufacturing method>>

[0027] The sintered body manufacturing method according to the embodiment comprises the following steps.

S1. Preparation step: A raw material powder containing an iron-based metal powder is prepared.
S2. Molding step: The raw material powder is subjected to uniaxial pressing using a die to produce a green compact having an overall average relative density of 93% or more.
S3. Machining step: The green compact is machined to produce a machined compact.
S4. Sintering step: The machined compact is sintered to obtain a sintered body.
S5. Finishing step: Finish machining is performed so that the actual dimensions of the sintered body are closer to its design dimensions.

[0028] These steps will be described in detail.

<<S1. Preparation step>>

[Metal powder]

[0029] The metal powder is a main material forming the sintered body, and examples of the metal powder include an iron powder and an iron alloy powder composed mainly of iron. Typically, the metal powder used is a pure iron powder or an iron alloy powder. The "iron powder composed mainly of iron" means that the iron alloy contains, as its component, elemental iron in an amount of more than 50% by mass, preferably 80% by mass or more, and more preferably 90% by mass or more. Examples of the iron alloy include an alloy containing at least one alloying element selected from Cu, Ni, Sn, Cr, Mo, Mn, and C. The above alloying elements contribute to improvement in the mechanical properties of the iron-based sintered body. Among the above alloying elements, Cu, Ni, Sn, Cr, Mn, and Mo are contained in a total amount of from 0.5% by mass to 5.0% by mass inclusive and from 1.0% by mass to 3.0% by mass inclusive. The content of C is from 0.2% by mass to 2.0% by mass inclusive and from 0.4% by mass to 1.0 mass inclusive. The metal powder used may be an iron powder, and a powder of any of the above alloying elements (an alloying powder) may be added to the iron powder. In this case, the component of the metal powder in the raw material powder is iron. However, the iron reacts with the alloying element during sintering in the subsequent sintering step and is thereby alloyed. In the raw material powder, the content of the metal powder (including the alloying powder) is, for example, 90% by mass or more and is 95% by mass or more. The metal powder used may be produced by, for example, a water atomization method, a gas atomization method, a carbonyl method, or a reduction method.

[0030] The average particle diameter of the metal powder is, for example, from 20 μm to 200 μm inclusive and from 50 μm to 150 μm inclusive. When the average particle diameter of the metal powder is within the above range, the metal powder is easy to handle and is easily pressure-molded in the subsequent molding step (S2).

When the average particle diameter of the metal powder is 20 μm or more, the flowability of the raw material powder can be easily ensured. When the average particle diameter of the metal powder is 200 μm or less, a sintered body with a dense structure can be easily obtained. The average particle diameter of the metal powder is the average particle diameter of the particles included in the metal powder and is a particle diameter (D50) at which a cumulative volume in a volumetric particle size distribution measured by a laser diffraction particle size distribution measurement apparatus is 50%. The use of the fine-grain metal powder allows the surface roughness of the sintered body to be reduced and its corner edges to be sharpened.

[Others]

[0031] In press forming using a die, a raw material powder prepared by mixing a metal powder and an internal lubricant is generally used to prevent the metal powder from sticking to the die. However, in this example, the raw material powder contains no internal lubricant. When the raw material powder contains an internal lubricant, the content of the internal lubricant is 0.2% by mass or less based on the total mass of the raw material powder. This is because a reduction in the ratio of the metal powder in the raw material powder is prevented to obtain a green compact with a relative density or 93% or more in the molding step described later. However, the raw material powder is allowed to contain a small amount of an internal lubricant so long as a green compact with a relative density or 93% or more can be produced in the subsequent molding step. The internal lubricant used can be a metallic soap such as lithium stearate or zinc stearate.

[0032] To prevent the occurrence of chipping and cracking in the green compact in the machining step described later, an organic binder may be added to the raw material powder. Examples of the organic binder include polyethylene, polypropylene, polyolefin, polymethyl methacrylate, polystyrene, polyvinyl chloride, polyvinylidene chloride, polyamide, polyester, polyether, polyvinyl alcohol, vinyl acetate, paraffin, and various waxes. The organic binder may be added as needed or may not be added. When the organic binder is added, the amount of the organic binder added is such that a green compact with a relative density or 93% or more can be produced in the subsequent molding step.

<<S2. Molding step>>

[0033] In the molding step, a die is used to uniaxial press the raw material powder to thereby produce a green compact. The die used for the uniaxial pressing includes a die block and a pair of punches to be fitted into upper and lower openings of the die block. The raw material powder filled into a cavity of the die block is compressed by the upper and lower punches to thereby produce a green compact. The green compact that can be formed using this die has a simple shape. Examples of the simple shape include a circular columnar shape, a circular tubular shape, a prismatic columnar shape, and a prismatic tubular shape. A punch having a projection or recess on its punching surface may be used. In this case, a recess or projection corresponding to the projection or recess of the punch is formed in the green compact having the simple shape. The green compact having the simple shape is intended to include such a green compact having a recess or projection.

[0034] The pressure (contact pressure) during the uniaxial pressing may be 600 MPa or higher. By increasing the contact pressure, the relative density of the green compact can be increased. The contact pressure is preferably 1,000 MPa or higher. The contact pressure is more preferably 1,500 MPa or higher. The upper limit of the contact pressure is not particularly specified.

[External lubricant]

[0035] In the uniaxial molding, it is preferable to apply an external lubricant to inner circumferential surfaces of the die (the inner circumferential surface of the die block and the pressing surfaces of the punches) in order to prevent the metal powder from sticking to the die. The external lubricant used may be a metallic soap such as lithium stearate or zinc stearate. Alternatively, the external lubricant used may be a fatty acid amide such as lauric acid amide, stearic acid amide, or palmitic acid amide or a higher fatty acid amide such as ethylene bisstearic acid amide.

[0036] The overall average relative density of the green compact obtained by uniaxial pressing is 93% or more. The overall average relative density of the green compact is preferably 95% or more, more preferably 96% or more, and still more preferably 97% or more. The overall average relative density of the green compact can be determined as follows. Cross sections of the green compact that intersect the direction of a pressing axis (preferably cross sections perpendicular to the pressing axis direction) are taken at a position near the center in the pressing axis direction, a position near one end, and a position near the other end. Then the cross sections are subjected to image analysis. More specifically, first, images of a plurality of viewing fields are captured in each cross section. For example, images of 10 or more viewing fields having an area of 500 μm × 600 μm = 300,000 μm^2 are captured in each cross section. Preferably, the images of the viewing fields are captured in each cross section from positions distributed uniformly as much as possible. Next, the captured image of each viewing field is subjected to binarization processing to determine the ratio of the area of the metal particles in the viewing field, and the ratio of the area is regarded as the relative density in the viewing field. Then the relative densities determined in the viewing fields are averaged to compute the overall average relative density of the green compact. The po-

sition near one end (the other end) is, for example, a position within 3 mm from a surface of the green compact.

<<S3. Machining step>>

[0037] In the machining step, after the green compact has been produced by uniaxial pressing, the green compact is machined without sintering. The machining is typically cutting, and a cutting tool is used to machine the green compact into a prescribed shape. Examples of the cutting include milling and lathe turning. Examples of the milling include drilling. Examples of the cutting tool used for drilling include a drill and a reamer, and examples of the cutting tool used for milling include a milling cutter and an end mill. Examples of the cutting tool used for lathe turning include a turning tool and an indexable cutting insert. Moreover, the cutting may be performed using a hob, a broach, a pinion cutter, etc. A machining center that can automatically perform a plurality of types of processing may be used for machining.

[0038] The concept of machining will be described with reference to conceptual illustrations in Fig. 1. An upper illustration in Fig. 1 schematically shows how a green compact 200 is machined with a cutting tool 100, and a lower illustration schematically shows how a solidified metal body 300 is machined with the cutting tool 100. As shown in the upper illustration in Fig. 1, in the green compact 200 formed by packing metal particles 202 under pressure, the green compact 200 is machined such that the metal particles 202 are torn off the surface of the green compact 200 by the cutting tool 100. Therefore, machining chips 201 generated as a result of machining are composed of metal powder of metal particles 202 separated from the green compact 200. The powdery machining chips 201 can be reused without melting. When clusters of aggregated metal particles 202 are present, the clusters may be pulverized as needed. As shown in the lower illustration in Fig. 1, the solidified metal body 300 is machined such that the surface of the solidified metal body 300 is shaved off by the cutting tool 100. Machining chips 301 generated by machining are composed of elongated structures and must be melted for reuse.

[0039] Before the machining, the surface of the green compact may be coated or impregnated with a volatile or plastic solution containing an organic binder dissolved therein in order to prevent chipping and cracking from occurring in the surface layer of the green compact during machining.

[0040] The green compact may be machined while compressive stress is applied to the green compact in such a direction that the tensile stress acting on the green compact is counteracted to thereby prevent chipping and cracking from occurring in the green compact. For example, when the green compact is broached to form a machined hole, strong tensile stress acts on a portion near an opening of the machined hole from which the broach protrudes when it pierces the green compact. One method for applying the compressive stress that counteracts the tensile stress to a green compact is to stack a plurality of green compacts one on top of another. It is preferable to dispose a dummy green compact, a plate material, etc. below the lowermost green compact. When a plurality of green compacts are stacked one on top of another, the lower surface of an upper green compact is pressed against the upper surface of a lower green compact, and compressive stress is thereby applied to the lower surface. When broaching is performed on the stacked green compacts from above, chipping and cracking can be effectively prevented from occurring near the openings of the machined hole which are formed on the lower surfaces of the green compacts and from which the broach protrudes. When a machined groove is formed in a green compact by milling, strong tensile stress acts on a portion near an end of the machined groove. To address this problem, a plurality of green compacts are arranged in the moving direction of the milling cutter such that compressive stress acts on portions corresponding to the ends of the groove.

<<S4. Sintering step>>

[0041] In the sintering step, the machined compact obtained by machining the green compact is sintered. By sintering the green compact, a sintered body in which the particles of the metal powder are in contact with each other and bonded together is obtained. To sinter the green compact, well-known conditions suitable for the composition of the metal powder can be used. For example, when the metal powder is an iron powder or an iron alloy powder, the sintering temperature is, for example, from 1,100°C to 1,400°C and from 1,200°C to 1,300°C inclusive. The sintering time is, for example, from 15 minutes to 150 minutes inclusive and from 20 to 60 minutes inclusive.

[0042] The degree of machining in the machining step may be adjusted according to the difference between the actual dimensions of the sintered body and its design dimensions. The machined compact prepared by machining the high-density green compact with a relative density or 93% or more contracts substantially uniformly during sintering. Therefore, by adjusting the degree of machining in the machining step according to the difference between the actual dimensions after sintering and the design dimensions, the actual dimensions of the sintered body can be very close to the design dimensions. This allows time and effort in the subsequent finish machining to be reduced. When a machining center is used for the machining, the degree of machining can be easily adjusted.

<<S5. Finishing step>>

[0043] In the finishing step, the surface of the sintered body is, for example, polished. The surface roughness of the sintered body is thereby reduced, and the dimen-

sions of the sintered body are adjusted to the design dimensions.

<<Outline of sintered body>>

[0044] With the sintered body manufacturing method described above, a sintered body with an overall average relative density of 93% or more can be obtained. The overall average relative density of the sintered body is approximately the same as the overall average relative density of the unsintered green compact. The overall average relative density of the sintered body is preferably 95% or more, more preferably 96% or more, and still more preferably 97% or more. The larger the average relative density, the higher the strength of the sintered body.

[0045] The overall average relative density of the sintered body can be determined as follows. Cross sections of the sintered body that intersect the pressing axis direction (preferably cross sections perpendicular to the pressing axis direction) are taken at a position near the center in the pressing axis direction, a position near one end, and a position near the other end. Then the cross sections are subjected to image analysis. More specifically, first, images of a plurality of viewing fields are captured in each cross section. For example, images of 10 or more viewing fields having an area of 500 μm $\times$ 600 μm = 300,000 μm^2 are captured in each cross section. Preferably, the images of the viewing fields are captured in each cross section from positions distributed uniformly as much as possible. Next, the captured image of each viewing field is subjected to binarization processing to determine the ratio of the area of the metal particles in the viewing field, and the ratio of the area is regarded as the relative density in the viewing field. Then the relative densities determined in the viewing fields are averaged to compute the overall average relative density of the green compact. The pressing axis direction of the sintered body can be easily found by observing the deformation state of the metal powder in the cross sections of the sintered body because the sintered body has been uniaxially pressed in its production process. The position near one end (the other end) is, for example, a position within 3 mm from a surface of the green compact.

<Production examples>

[0046] In production examples, the sintered body manufacturing method in the embodiment and a conventional sintered body manufacturing method were used to produce assemblies 1 shown in Fig. 2 and each including planetary gears 2 and a planetary carrier 3. Each planetary gear 2 is a helical gear having teeth 20 extending obliquely to an axial line as shown in Fig. 3 (see a dash-dot line). As shown in Figs. 2 and 4, the planetary carrier 3 includes a disk-shaped first member 31 and a second member 32 having three bridge portions 32b formed in its disk portion 32s.

<<Sample A: sintered body manufacturing method in embodiment>>

[0047] First, a raw material powder was prepared by mixing an Fe-2 mass % Ni-0.5 mass % Mo alloy powder with 0.3% by mass of C (graphite) powder. The true density of the raw material powder was about 7.8 g/cm^3.

[0048] Next, the raw material powder was pressure-molded by uniaxial pressing to produce the following three types of green compacts. The molding pressure was 1,200 MPa for each of these cases.

- A cylindrical green compact for a planetary gear 2 diameter: 50 mm, height: 20 mm
- A disk-shaped green compact for the first member 31 diameter: 130 mm, height: 35 mm

[0049] A cylindrical green compact for the second member 32 diameter: 130 mm, height: 35 mm

[0050] The overall average relative densities of these three types of green compacts were determined and found to be 93% or more. As described in «S2. Molding step» above, the average relative density of each green compact was determined as follows. Cross sections of the green compact were taken at a position near the center in the pressing axis direction and positions near the opposite ends. Images of 10 or more viewing fields having an area of 500 μm $\times$ 600 μm = 300,000 μm^2 were captured in each cross section and subjected to image analysis. Specifically, the average relative density of the green compact was about 96.2%. The average relative density was converted to an average bulk density, and the average bulk density of the green compact was 7.5 g/cm^3.

[0051] Next, a commercial machining center was used to machine each of the green compacts produced, and machined compacts having desired shapes were thereby produced. The green compacts for the planetary gears 2 were machined to form teeth 20 inclined 50° with respect to their axial line. The green compact for the first member 31 was machined to form a boss portion 31b by shaving as shown in Fig. 1. Then a hole was formed at the center of the boss portion 31b, and teeth of an internal gear were formed inside the hole. The green compact for the second member 32 was machined to form the bridge portions 32b by shaving. Then, as shown in the lower illustration in Fig. 4, an inner circumferential surface portion (a portion indicated by a black arrow) included in a base portion of each bridge portion 32b and connected to the disk portion 32s was formed into an R shape. When the inner circumferential surface portion is formed into an R shape, the strength of the bridge portions 32b can be improved. During the machining of any of the above green compacts, no chipping and cracking occurred in the green compacts. The machining chips generated by machining were composed of metal powder of metal particles separated from the green compacts.

[0052] Next, the machined compacts were sintered to

produce the planetary gears 2 and planetary carrier 3 composed of the sintered bodies. During the sintering, no chipping and cracking occurred in the sintered bodies. Finally, the planetary gears 2 and the planetary carrier 3 were, for example, polished so that their dimensions were closer to the design dimensions and their surface roughness was reduced.

[0053] The average relative densities of the planetary gears 2 and the planetary carrier 3 in sample A were determined and found to be about 93% or more. As described in <<Sintered body>> above, the average relative density of each of the planetary gears 2 and the planetary carrier 3 (sintered bodies) was determined as flows. Cross sections were taken at a position near the center in the pressing axis direction and positions near opposite ends. Images of 10 or more viewing fields having an area of 500 μm $\times$ 600 μm = 300,000 μm^2 were subjected to image analysis. Specifically, the average relative density of each of the planetary gears 2 and the planetary carrier 3 was about 96.2%. The average relative density was converted to an average bulk density, and the average bulk density of each of the planetary gears 2 and the planetary carrier 3 was 7.5 g/cm^3. The viewing fields captured in the cross sections include portions of the teeth 20 of the planetary gears 2. The relative density of only these portions was determined and found to be 96.2%.

[0054] The planetary gears 2 and the planetary carrier 3 in sample A had mechanical strength comparable to that of planetary gears and a planetary carrier formed from solidified metal bodies produced by a melting method. It was therefore found that the planetary gears 2 and the planetary carrier 3 in sample A can be sufficiently used for components of automobiles.

<<Sample B: conventional sintered body manufacturing method>>

[0055] The same raw material powder as sample A was prepared and subjected to near net shape molding to produce green compacts having a shape close to the shape of the planetary gears 2 and a green compact having a shape close to the shape of the planetary carrier 3. Since the planetary gears 2 are helical gears, a rotary press was used for near net shape molding of the planetary gears 2. With the rotary press, the inclination of the teeth 20 with respect to the axial line cannot be 45° or more. With the rotary press, the available molding pressure was much lower than 600 MPa.

[0056] The near-net shaped green compacts were sintered and subjected to finish machining to thereby produce planetary gears 2 and a planetary carrier 3 in sample B. For each of the planetary gears 2 and the planetary carrier 3 in sample B, the relative densities of viewing fields in cross sections were determined by the same method as that for sample A. The relative densities were different for different viewing fields. Specifically, in the teeth 20 of the planetary gear 2, the average relative density was about 88.5% (average bulk density: 6.9 g/cm^3). In portions other than the teeth 20, the average relative density was about 89.7% (average bulk density: 7.0 g/cm^3). The overall average relative density of sample B was about 89%.

[0057] The mechanical strength of the planetary gears 2 and the planetary carrier 3 in sample B was much worse than that of a planetary gear and a planetary carrier formed from solidified metal bodies produced by a melting method. In particular, since the relative density of the teeth 20 of the planetary gear 2 to which high stress is applied during use is low, the planetary gears 2 and the planetary carrier 3 in sample B may be unsuitable for components of automobiles.

<Applications>

[0058] The sintered body manufacturing method in the embodiment can be preferably used to produce a sintered member having a complicated shape that is difficult to produce only by pressure molding using a die. The sintered body manufacturing method in the embodiment can be used to produce, for example, sprockets, rotors, gears, rings, flanges, pulleys, vanes, bearings, etc. used for machines such as automobiles.

Reference Signs List

[0059]

1	assembly
2	planetary gear, 20 tooth
3	planetary carrier
31	first member, 31b boss portion
32	second member, 32s disk portion, 32b bridge portion
100	cutting tool
200	green compact, 201 machining chips, 202 metal particle
300	solidified metal body, 301 machining chips

Claims

1. A method for manufacturing a sintered body, the method comprising:

a preparation step of preparing a raw material powder containing an iron-based metal powder;
a molding step of subjecting the raw material powder to uniaxial pressing using a die to produce a green compact having an overall average relative density of 93% or more;
a machining step of machining the green compact to produce a machined compact; and
a sintering step of sintering the machined compact to obtain a sintered body.

2. The method for manufacturing a sintered body ac-

cording to claim 1, wherein, in the machining step, the green compact is machined into a helical gear shape.

3. The method for manufacturing a sintered body according to claim 1 or 2, wherein the uniaxial pressing is performed at a pressure of 600 MPa or higher.

4. The method for manufacturing a sintered body according to any one of claims 1 to 3, wherein the machining step is performed using a cutting method.

5. The method for manufacturing a sintered body according to any one of claims 1 to 4, wherein the machining step is performed while compressive stress is applied to the green compact in such a direction that tensile stress acting on the green compact from a working tool is counteracted.

6. A sintered body composed of an iron-based material comprising:

an average relative density of the whole sintered body being 93% or more.

7. The sintered body according to claim 6, wherein the sintered body is a helical gear.

8. The sintered body according to claim 7, wherein the helical gear has teeth inclined 30° or more with respect to an axial line of the helical gear.

FIG. 1

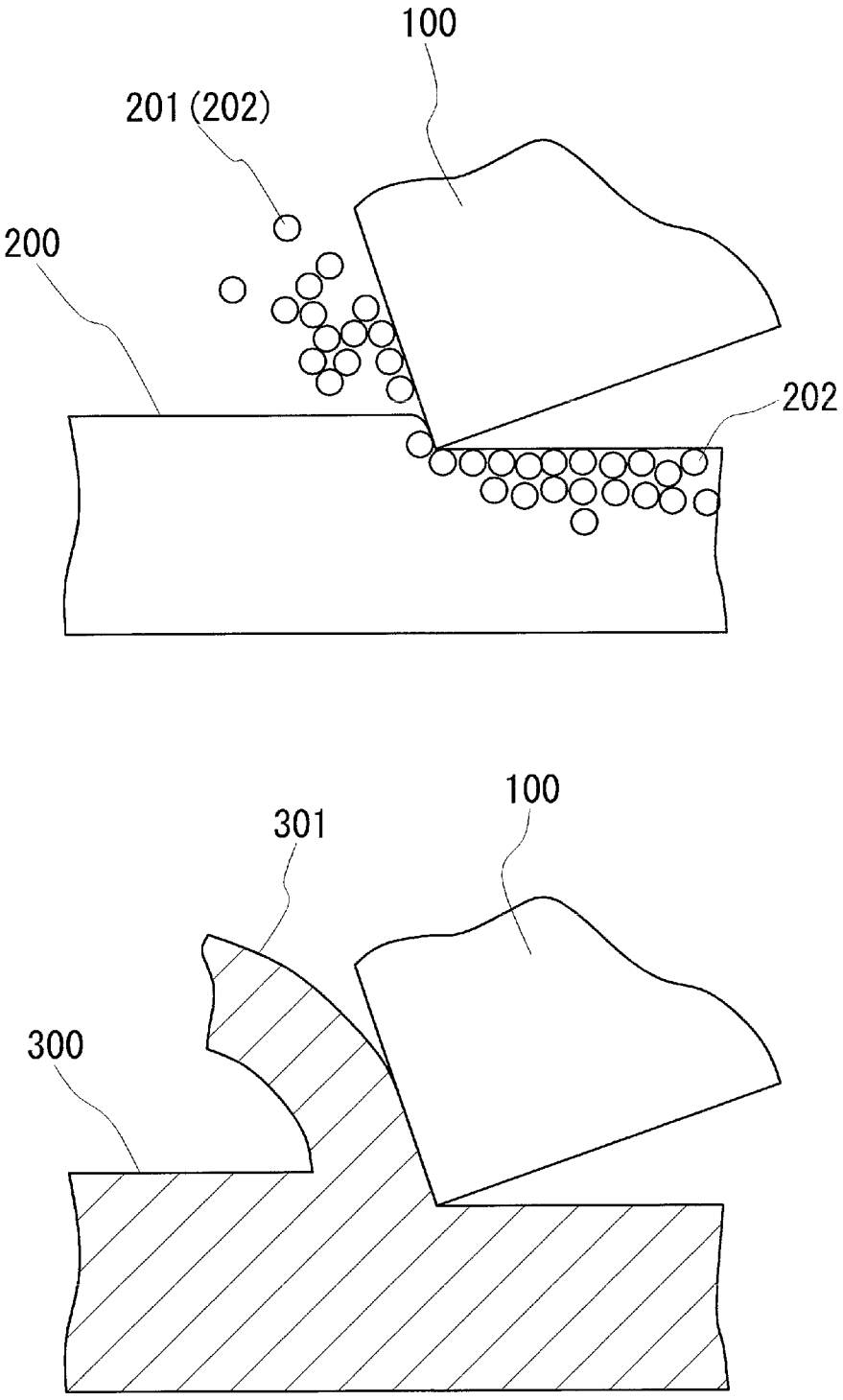


FIG. 2

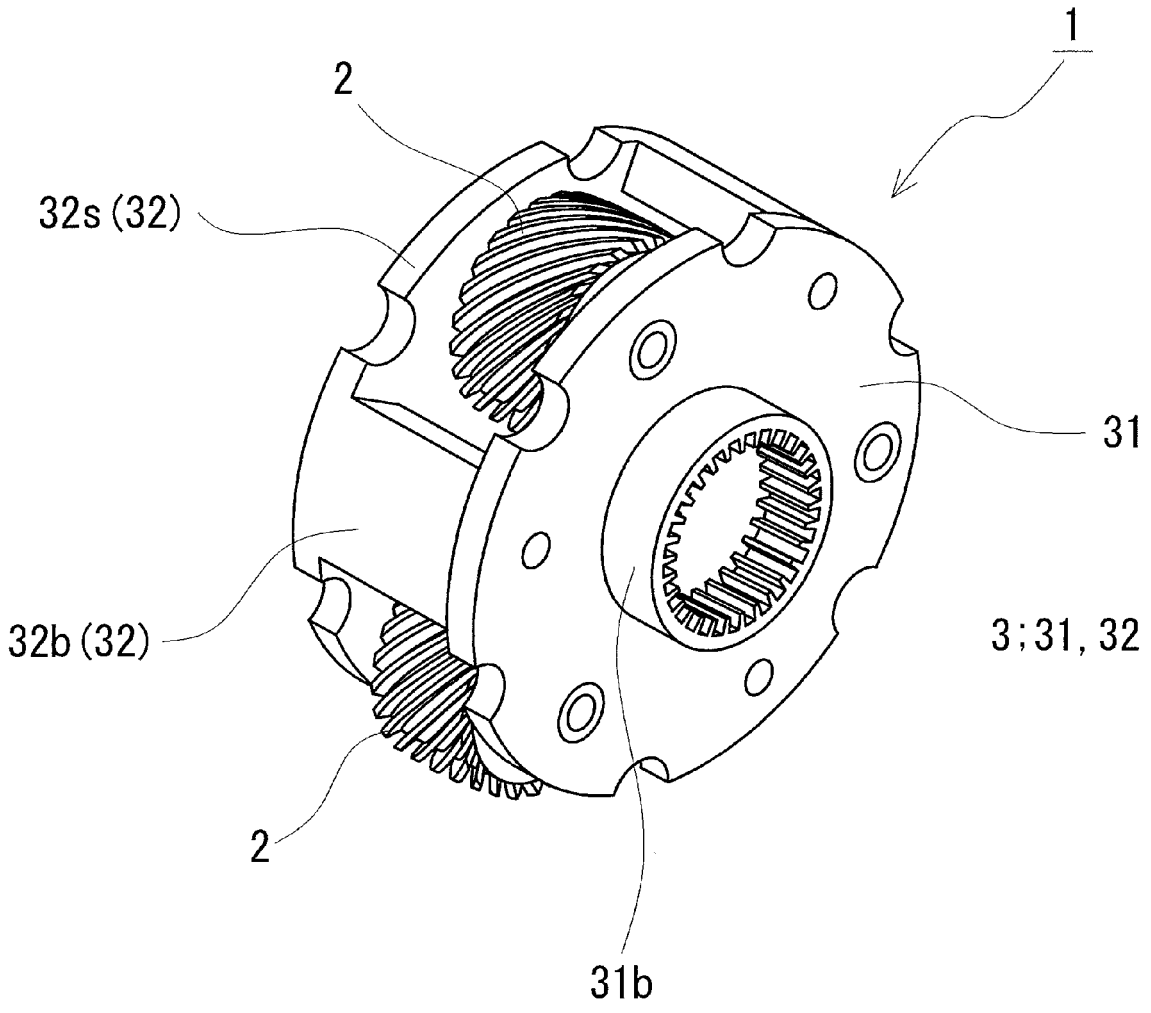


FIG. 3

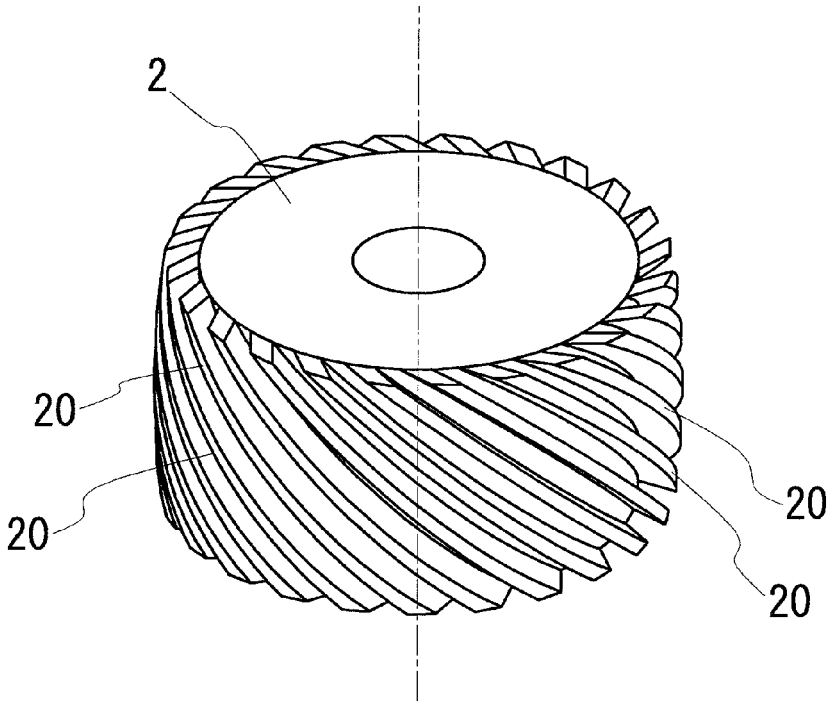
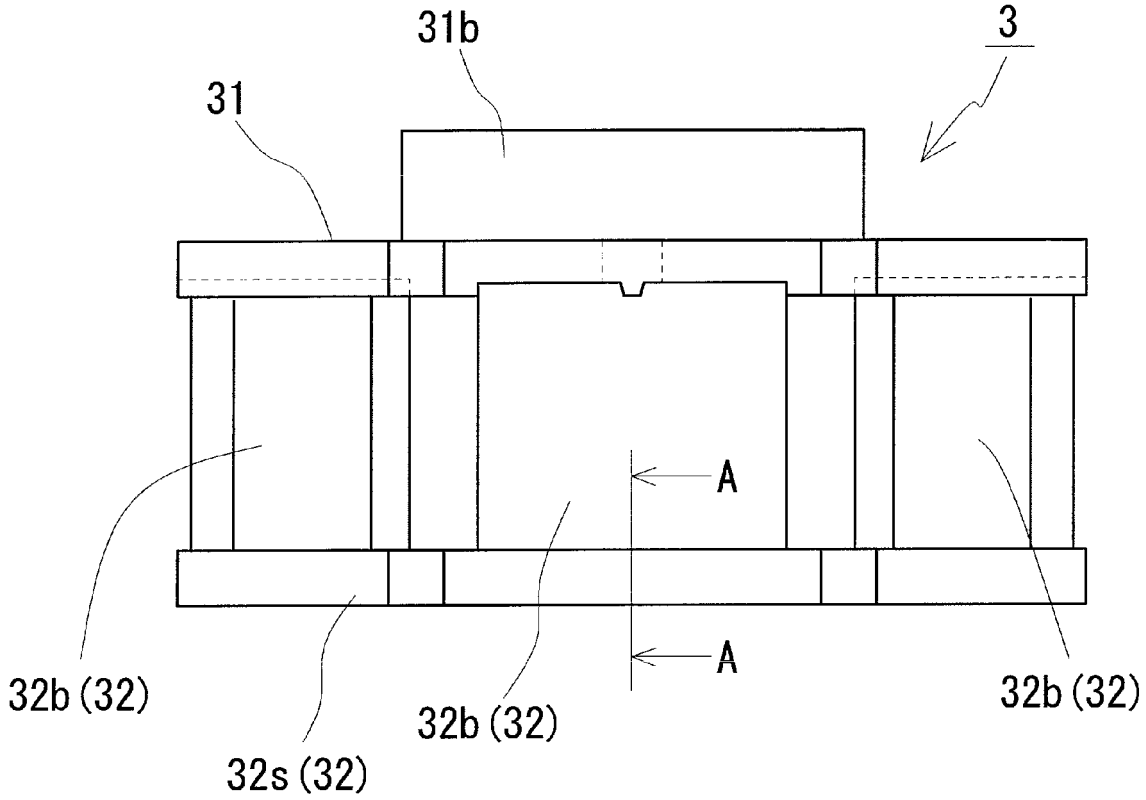
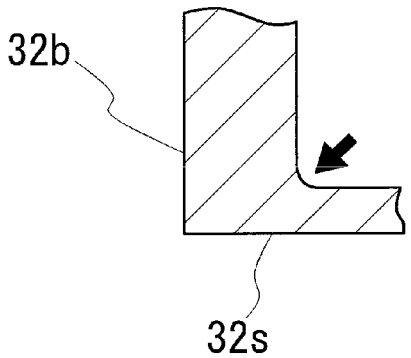


FIG. 4





INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/014145

A. CLASSIFICATION OF SUBJECT MATTER
B22F3/10(2006.01)i, *B22F5/08*(2006.01)i, *C22C38/00*(2006.01)n

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)
B22F3/10, B22F5/08, C22C38/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2017
Kokai Jitsuyo Shinan Koho 1971-2017 Toroku Jitsuyo Shinan Koho 1994-2017

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2004-323939 A (Sumitomo Electric Sintered Alloy, Ltd.), 18 November 2004 (18.11.2004), claims 1 to 2; paragraphs [0021], [0030], [0043]; fig. 1 (Family: none)	1,3-4
X Y	JP 11-315305 A (Injex Corp.), 16 November 1999 (16.11.1999), paragraphs [0024], [0144] (Family: none)	6 7-8
Y	JP 8-104904 A (Mitsubishi Materials Corp.), 23 April 1996 (23.04.1996), paragraph [0002] (Family: none)	7-8

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 April 2017 (28.04.17)	16 May 2017 (16.05.17)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3,Kasumigaseki,Chiyoda-ku, Tokyo 100-8915,Japan	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2017/014145

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 7-145442 A (Alps Electric Co., Ltd.), 06 June 1995 (06.06.1995), & US 5509975 A	1-8

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2016077069 A **[0002]**
- JP 2007077468 A **[0004]**