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

(11) EP 2 650 065 A1

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

(43) Date of publication:
16.10.2013 Bulletin 2013/42

(21) Application number: **11847431.1**

(22) Date of filing: **08.12.2011**

(51) Int Cl.:
B22F 3/02 *(2006.01)*

(86) International application number:
PCT/JP2011/078414

(87) International publication number:
WO 2012/077750 (14.06.2012 Gazette 2012/24)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **08.12.2010 JP 2010273174**

(71) Applicant: **Aida Engineering, Ltd.**
Sagamihara-shi, Kanagawa 252-5181 (JP)

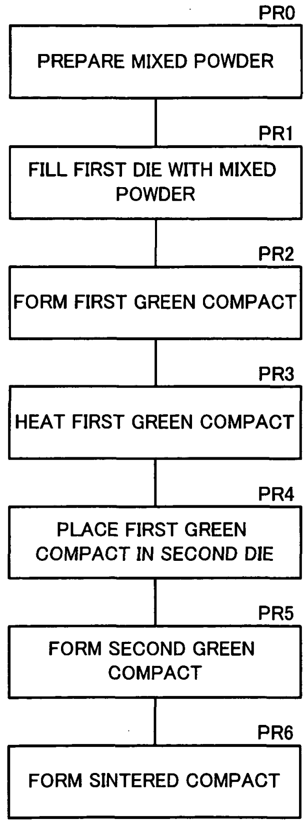
(72) Inventor: **HIRAI, Yoshiki**
Sagamihara-shi, Kangawa 252-5181 (JP)

(74) Representative: **Roos, Peter**
Roospatent
Bavariaring 20
80336 München (DE)

(54) **METHOD FOR MANUFACTURING HIGH-STRENGTH SINTER-MOLDED COMPACT, AND DEVICE FOR MANUFACTURING SAME**

(57) A method for producing a high-strength sintered compact includes a press molding step and a sintering step, the press molding step including a first press molding step and a second press molding step, a heating step being provided between the first press molding step and the second press molding step, the first press molding step applying a first pressure to the mixed powder in a first die at room temperature that is less than a melting point of the lubricant powder to form a primary green compact, the heating step heating the primary green compact to the melting point of the lubricant powder, and the second press molding step applying a second pressure to the primary green compact in a second die at the melting point of the lubricant powder to form a densified secondary green compact, the second die being preheated to the melting point of the lubricant powder.

FIG.1



EP 2 650 065 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a method for producing a high-strength sintered compact and a high-strength sintered compact production system that press a mixed powder twice to form a densified green compact, and sinter the green compact to produce a sintered compact that exhibits improved mechanical strength.

BACKGROUND ART

[0002] Powder metallurgy is a technique that normally presses (compresses) a metal powder to form a green compact having a given shape, and heats the green compact to a temperature around the melting point of the metal powder to promote intergranular coupling (solidification) (sintering process). This makes it possible to inexpensively produce a sintered compact (e.g., mechanical part) that has a complex shape and high dimensional accuracy.

[0003] An increase in mechanical strength of a green compact has been desired since a further reduction in size and weight of mechanical parts. The mechanical strength of a green compact increases significantly (hyperbolically) as the density of the green compact increases. For example, a method that mixes a lubricant into a metal powder, and press- molds the metal powder while reducing friction resistance has been proposed (e.g. Patent Document 1 (JP- A- 1- 219101)) . Various other methods have been proposed in order to achieve higher density. These methods can be roughly classified into a method that improves the lubricant, and a method that improves the press molding/ sintering process.

[0004] Examples of the method that improves the lubricant include a method that utilizes a composite of carbon molecules obtained by combining a ball- like carbon molecule with a sheet- like carbon molecule as the lubricant (see Patent Document 2 (JP- A- 2009- 280908), for example), and a method that utilizes a lubricant having a penetration at 25°C of 0.3 to 10 mm (see Patent Document 3 (JP- A- 2010- 37632), for example) . These methods aim at reducing the friction resistance between the metal powder and a die.

[0005] Examples of the method that improves the press molding/ sintering process include a warm molding/ sinter powder metallurgy technique (see Patent Document 4 (JP- A- 2- 156002), for example), a double press/ double sinter powder metallurgy technique (see Patent Document 5 (JP- A- 4- 231404), for example), and a single press/ sinter powder metallurgy technique (see Patent Document 6 (JP- A- 2001- 181701), for example) .

[0006] According to the warm molding/sinter powder metallurgy technique, a metal powder prepared by mixing a solid lubricant and a liquid lubricant is preheated to melt part or the entirety of the lubricant, and disperse the lubricant between the metal powder particles. This technique thus reduces the inter-particle friction resistance and the friction resistance between the particles and a die to improve formability. According to the double press/ double sinter powder metallurgy technique, an iron powder mixture that contains an alloying component is compressed in a die to obtain a green compact, the green compact is presintered at 870°C for 5 minutes, and compressed to obtain a presintered body, and the presintered body is sintered at 1000°C for 5 minutes to obtain a sintered body (part). According to the single press/sinter powder metallurgy technique, a die is preheated, and a lubricant is caused to electrically adhere to the inner side of the die. The die is filled with a heated iron-based powder mixture (iron-based powder+lubricant powder), and the powder mixture is press-molded at a given temperature to obtain an iron-based powder molded body. The iron-based powder molded body is sintered, and subjected to bright quenching and annealing to obtain an iron-based sintered body.

[0007] The above methods that improve the lubricant or the press molding/sintering process are complex, may increase cost, and have a problem in that handling of the material is difficult or troublesome. The density of the green compact achieved by the above methods is about 7.4 g/cm^3 (94% of the true density) at a maximum in spite of the above disadvantages. When a residue remains due to combustion of the lubricant, the quality of the resulting green compact deteriorates. Therefore, the density of the green compact is limited to 7.3 g/cm^3 or less in actual applications. The green compact exhibits insufficient mechanical strength when the density of the green compact is 7.3 g/cm^3 or less.

[0008] In particular, when producing a magnetic core for an electromechanical device (e.g., motor or transformer) using a green compact, a good magnetic core may not be produced when the density of the green compact is 7.3 g/cm^3 or less. It is necessary to further increase the density of a green compact in order to reduce loss (iron loss and hysteresis loss), and increase magnetic flux density (see the document presented by Toyota Central R & D Labs., Inc. in Autumn Meeting of Japan Society of Powder and Powder Metallurgy, 2009).

[0009] A double molding/ single sinter (anneal) powder metallurgy technique (see Patent Document 7 (JP- A- 2002- 343657), for example) has been proposed as a method that produces a magnetic- core green compact. Specifically, a dust core is produced by preforming a magnetic metal powder that is coated with a coating that contains a silicone resin and a pigment to obtain a preformed body, subjecting the preformed body to a heat treatment at 500°C or more to obtain a heat- treated body, and compressing the heat- treated body. If the heat treatment temperature is less than 500°C, breakage may occur during compression molding. If the heat treatment temperature is more than 1000°C, the insulating coating may be decomposed (i.e., insulating properties may be impaired) . Therefore, the heat treatment temperature is set to 500 to 1000°C. The high- temperature treatment is performed under vacuum, an inert gas atmosphere, or a reducing gas atmosphere in order to prevent oxidation of the preformed body. The double molding/ single sinter powder metallurgy technique is very complex, individualized, and difficult to implement as compared with other techniques, and significantly increases the production cost. Therefore, the double molding/ single sinter powder metallurgy technique is not suitable for mass production.

SUMMARY OF THE INVENTION

TECHNICAL PROBLEM

[0010] The above methods and systems (Patent Documents 1 to 7) cannot meet industrial demands for inexpensive and reliable production of a sintered compact that exhibits high mechanical strength. It has been generally considered that the mechanical strength of a sintered compact depends on the final sintering process. This is obvious from the fact that Patent Documents 1 to 7 disclose the details of the annealing process and the sintering process at a high temperature, but do not disclose the details of the press molding step, the relationship between the density and the specification, functions, and pressure of the press molding device, analysis of the limit thereof, and improvements thereof

[0011] As described above, a further increase in mechanical strength has been desired along with a reduction in size and weight of mechanical parts and the like, and there is an urgent need to develop a method and a system that can reliably, stably, and inexpensively produce a high-strength sintered compact.

[0012] An object of the invention is to provide a method for producing a high-strength sintered compact and a high-strength sintered compact production system that can reliably, stably, and inexpensively produce a sintered compact that exhibits high mechanical strength.

SOLUTION TO PROBLEM

[0013] The press molding process forms a mixed powder to have a specific shape, and has been considered to be a preliminary mechanical process that is performed in the preceding stage of the high-temperature sintering process. Specifically, an increase in strength has been achieved by the final sintering process.

[0014] However, the mechanical strength of the sintered compact can be significantly improved using a normal sintering process by significantly improving the density of the green compact by improving the press molding process that has been considered to be a preliminary mechanical process.

[0015] The invention was conceived based on studies of the effectiveness of a lubricant during pressing, the compressed limit when using a lubricant powder, the spatial distribution of a lubricant powder in a mixed powder, the spatial distribution and the behavior of a basic metal powder and a lubricant powder, the state of a residue (solidified grains), partial diffusion of metal particles due to vaporization of a lubricant, and the final disposition state of a lubricant, and analysis of the characteristics (e.g., compressed limit) of a normal press molding device, and their effects on the density (strength) of a green compact.

[0016] As illustrated in FIGS. 8A and 8B, a large amount of waste (e.g., residue) 108 or a number of large pores 109 remain in a green compact 115 when using a related-art method. It was found that the density (strength) of the green compact cannot be improved to a value equal to or higher than a given value even if the applied pressure is significantly increased (or increased as much as possible) in this state. The invention aims at improving the density of the green compact by solving the above problem, and achieving an increase in strength via sintering to significantly improve the strength of the final sintered compact.

[0017] According to several aspects of the invention, a primary green compact is formed by a first pressing step while maintaining a lubricant in a powdery state, and the lubricant is liquefied by heating to change the state of the lubricant in the primary green compact, A densified secondary green compact is formed by performing a second pressing step on the primary green compact, and the secondary green compact is sintered to form a high-strength sintered compact. Specifically, several aspects of the invention may provide an epoch-making method and system that can reliably, stably, and inexpensively produce a high-strength sintered compact by positively and significantly increasing the density of a green compact (based on which densification via a sintering process is achieved) during the press molding process that has been considered to be a preliminary mechanical process.

(1) According to one aspect of the invention, there is provided a method for producing a high-strength sintered compact including:

a press molding step that applies pressure to a mixed powder to form a green compact, the mixed powder being a mixture of a basic metal powder and a lubricant powder; and
a sintering step that sinters the green compact to form a sintered compact that exhibits improved mechanical strength,
the press molding step including a first press molding step and a second press molding step, a heating step being provided between the first press molding step and the second press molding step,
the first press molding step applying a first pressure to the mixed powder in a first die at room temperature that is less than a melting point of the lubricant powder to form a primary green compact,
the heating step heating the primary green compact to the melting point of the lubricant powder,

and

the second press molding step applying a second pressure to the primary green compact in a second die at the melting point of the lubricant powder to form a densified secondary green compact, the second die being pre-heated to the melting point of the lubricant powder.

(2) In the method for producing a high-strength sintered compact, the lubricant powder may have a low melting point within the range of 90 to 190°C.
(3) In the method for producing a high-strength sintered compact, the mixed powder may be prepared by mixing a pure iron powder as the basic metal powder with 0.03 to 0.10 wt% of a zinc stearate powder as the lubricant powder, the first pressure may be selected to compress the mixed powder so that the primary green compact has a density of 7.0 to 7.5 g/cm^3, and the second pressure may be selected to compress the primary green compact so that the secondary green compact has a density of 7.75 g/cm^3.
(4) In the method for producing a high-strength sintered compact, the mixed powder may be prepared by mixing an Fe-Si alloy powder as the basic metal powder with 0.03 to 0.10 wt% of a zinc stearate powder as the lubricant powder, the first pressure may be selected to compress the mixed powder so that the primary green compact has a true density ratio of 70 to 85%, and the second pressure may be selected to compress the primary green compact so that the secondary green compact has a true density ratio of 85 to 95%..
(5) In the method for producing a high-strength sintered compact, the second pressure may be selected to be equal to the first pressure.
(6) According to one aspect of the invention, there is provided a high-strength sintered compact production system including:

a mixed powder feeding device that can externally supply a mixed powder that is a mixture of a basic metal powder and a lubricant powder that has a low melting point;
a first press molding device that applies a first pressure to the mixed powder in a first die to form a primary green compact, the first die being filled with the mixed powder using the mixed powder feeding device;
a heating device that heats the primary green compact removed from the first die to the melting point of the lubricant powder;
a second press molding device that includes a second die that can be pre-heated to the melting point of the lubricant powder in advance, and applies a second pressure to the primary green compact that has been heated and is placed in the pre-heated second die to form a densified secondary green compact; and
a sintering device that sinters the secondary green compact to form a sintered compact that exhibits improved mechanical strength.

(7) In the high-strength sintered compact production system, the heating device and the second press molding device may be formed by a heating/press molding device having a function of the heating device and a function of the second press molding device, the heating/press molding device may include a plurality of heating/press molding sub-devices, and each of the plurality of heating/press molding sub-devices can be selectively and sequentially operated in each cycle.

ADVANTAGEOUS EFFECTS OF THE INVENTION

[0018] According to the configuration (1), the high-strength sintered compact can be reliably and stably produced while significantly reducing the production cost.
[0019] According to the configuration (2), it is possible to ensure that the lubricant produces a sufficient lubricating effect during the first press molding step, and use a wide variety of lubricants.
[0020] According to the configurations (3) and (4), a sintered compact that exhibits high mechanical strength as compared with a sintered compact formed by a related-art method can be efficiently produced.
[0021] According to the configuration (5), the equipment cost of the press molding device can be reduced, and the press molding step can be easily implemented. Therefore, the production cost of the green compact can be further reduced.
[0022] According to the configuration (6), the method for producing a high-strength sintered compact (see (1) to (5)) can be reliably implemented, and the system can be easily implemented and handled.
[0023] According to the configuration (7), the system can be simplified as compared with the configuration (6). It is also possible to simplify the production line, and further facilitate handling. Moreover, the takt time of the first press molding step, the heating step, and the second press molding step can be made equal.

BRIEF DESCRIPTION OF DRAWINGS

[0024]

FIG 1 is a view illustrating a method for producing a high-strength sintered compact according to one embodiment of the invention.
FIG 2 is a front view illustrating a high-strength sintered compact production system (and its operation) according to a first embodiment of the invention.
FIG 3A is a view illustrating a mixed powder molding operation performed by a high-strength sintered compact production system according to the first embodiment of the invention, and illustrates a state in

which a primary green compact is formed in a first die.

FIG 3B is a view illustrating a mixed powder molding operation performed by a high-strength sintered compact production system according to the first embodiment of the invention, and illustrates a state in which a first die is filled with a mixed powder.

FIG 4 is a graph illustrating the relationship between the pressure and the density obtained by applying the pressure using a high-strength sintered compact production system according to the first embodiment of the invention (wherein the broken line A indicates a molding state in a first die, and the solid line B indicates a molding state in a second die).

FIG 5 is an enlarged cross-sectional view illustrating the internal state of the cross section of a secondary green compact formed using a high-strength sintered compact production system according to the first embodiment of the invention.

FIG 6A is an external perspective view illustrating a ring-like sintered compact (secondary green compact and primary green compact) formed using a high-strength sintered compact production system according to the first embodiment of the invention.

FIG 6B is an external perspective view illustrating an elongated cylindrical sintered compact (secondary green compact and primary green compact) formed using a high-strength sintered compact production system according to the first embodiment of the invention.

FIG 7 is a front view illustrating a high-strength sintered compact production system (and its operation) according to a second embodiment of the invention.

FIG 8A is an enlarged cross-sectional view illustrating the internal state of the cross section of a preliminary green compact heated by a related-art method, and a problem thereof (heating temperature: 500 to 700°C).

FIG 8B is an enlarged cross-sectional view illustrating the internal state of the cross section of a preliminary green compact heated by a related-art method, and a problem thereof (heating temperature: 700 to 1000°C).

DESCRIPTION OF EMBODIMENTS

[0025] Exemplary embodiments of the invention are described in detail below with reference to the drawings.

First embodiment

[0026] A high-strength sintered compact production system 1 according to a first embodiment of the invention includes a mixed powder feeding device 10, a first press molding device 20, a heating device 30, a second press molding device 40, and a sintering device 80, and can stably and reliably implement a method for producing a high-strength sintered compact that includes a press molding step that applies pressure to a mixed powder 100 that is a mixture of a basic metal powder and a lubricant powder to form a green compact 110 (115), and a sintering step that sinters the green compact 115 to form a sintered compact 120 that exhibits improved mechanical strength.

[0027] The method for producing a high-strength sintered compact according to the first embodiment is technically characterized in that the press molding step includes a first press molding step (PR2 in FIG. 1) and a second press molding step (PR5), a heating step (PR3) being provided between the first press molding step (PR2) and the second press molding step (PR5), the first press molding step (PR2) applies a first pressure P1 to the mixed powder 100 in a first die (lower die 21) at room temperature that is less than the melting point of the lubricant powder to form a primary green compact 110, the heating step (PR3) heats the primary green compact 110 to the melting point of the lubricant powder, and the second press molding step (PR5) applies a second pressure P2 to the primary green compact 110 in a second die (lower die 41) at the melting point of the lubricant powder to form a densified secondary green compact 115, the second die being pre-heated to the melting point of the lubricant powder.

[0028] As illustrated in FIG 1, the high-strength sintered compact production system 1 according to a first embodiment sequentially performs a mixed powder-filling step (PR1) that fills the first die with the mixed powder 100 prepared in a preparation step (PR0), a primary green compact-forming step (PR2), a heating step (PR3) that heats the primary green compact 110 to the melting point of the lubricant powder (i.e., increases the temperature of the primary green compact 110 to the melting point of the lubricant powder), a step (PR4) that places the heated primary green compact 110 in the second die, a secondary green compact-forming step (PR5), and a sintering step (PR6) that sinters the secondary green compact 115 to form a high-strength sintered compact 120.

[0029] The mixed powder 100 is a mixture of a basic metal powder and a lubricant powder that has a low melting point. The basic metal powder may include only one type of main metal powder, or may be a mixture of one type of main metal powder and one or more types of alloying component powder. The expression "low melting point" used herein in connection with the lubricant powder refers to a temperature (melting point) that is significantly lower than the melting point (temperature) of the basic metal powder, and can significantly suppress oxidation of the basic metal powder. The details thereof are described later.

[0030] As illustrated in FIG 2 that illustrates the high-strength sintered compact production system 1, the mixed powder feeding device 10 is disposed on the leftmost side (upstream side) of a high-density molding line. The mixed powder feeding device 10 is a means that fills the first die (lower die 21) included in the first press molding device 20 with the mixed powder 100. The mixed powder feeding device 10 has a function of storing a constant amount of the mixed powder 100, and a function of feeding a constant amount of the mixed powder 100. The mixed powder feeding device 10 can selectively move between the initial position (i.e., the position indicated by the solid line in FIGS. 2 to 3B) and the position over the first die (lower die 21) (i.e., the position indicated by the dotted line in FIGS. 3A and 3B).

[0031] Since it is important to uniformly and sufficiently fill the first die (lower die 21) with the mixed powder 100, the mixed powder 100 must be in a dry state. Specifically, since the shape of the cavity of the first die (lower die 21) corresponds to the shape of the product, it is necessary to uniformly and sufficiently fill the first die with the mixed powder 100 in order to ensure the dimensional accuracy of the primary green compact 110, even if the product has a complex shape, or has a narrow part.

[0032] In the first embodiment, the primary green compact 110 (secondary green compact 115) has a ring-like shape as illustrated in FIG 6A, and a cavity 22 of the first die has a shape corresponding to the shape of the primary green compact 110 (secondary green compact 115).

[0033] A solid lubricant that is in a dry state (fine particulate) at room temperature is used as the lubricant that is used to reduce the inter-particle friction resistance of the basic metal powder and the friction resistance between the basic metal powder and the inner side of the die. For example, since the mixed powder 100 exhibits high viscosity and low fluidity when using a liquid lubricant, it is difficult to uniformly and sufficiently fill the first die with the mixed powder 100.

[0034] It is also necessary for the lubricant to be solid and stably maintain a given lubricating effect during the primary green compact (110) molding step that is performed in the first die (21) at room temperature while applying the first pressure P1. The lubricant must stably maintain a given lubricating effect even if an increase in temperature has occurred to some extent as a result of applying the first pressure P1.

[0035] On the other hand, the melting point of the lubricant powder must be significantly lower than the melting point of the basic metal powder from the viewpoint of the relationship with the heating step (PR3) performed after the primary green compact (110) molding step, and suppression of oxidation of the basic metal powder.

[0036] In the first embodiment, the lubricant powder has a low melting point within the range of 90 to 190°C. The lower-limit temperature (90°C) is selected to be higher to some extent than the upper-limit temperature (80°C) of a temperature range (70 to 80°C) that is not reached even if an increase in temperature has occurred to some extent during the primary green compact molding step, while taking account of the melting point (e.g., 110°C) of other metallic soaps. This prevents a situation in which the lubricant powder is melted (liquefied) and flows during the primary green compact molding step.

[0037] The upper-limit temperature (190°C) is selected to be a minimum value from the viewpoint of lubricant powder selectivity, and is selected to be a maximum value from the viewpoint of suppression of oxidation of the basic metal powder during the heating step (PR3). Specifically, it should be understood that the lower-limit temperature and the upper-limit temperature of the above temperature range (90 to 190°C) are not threshold values, but are boundary values.

[0038] This makes it possible to selectively use an arbitrary metallic soap (e.g., zinc stearate or magnesium stearate) as the lubricant powder. Note that a viscous liquid such as zinc octylate cannot be used since the lubricant must be powdery.

[0039] In each example described later, a zinc stearate powder having a melting point of 120°C was used as the lubricant powder. Note that the invention does not employ a configuration in which a lubricant having a melting point lower than the die temperature during press molding is used, and the press molding step is performed while melting (liquefying) the lubricant (see Patent Document 6). If the lubricant is melted and flows out before completion of molding of the primary green compact 110, lubrication tends to be partially insufficient during the molding step, and sufficient press molding cannot be performed reliably and stably.

[0040] The lubricant powder is used in an amount (0.02 to 0.12 wt% of the total amount of the mixed powder) selected based on an empirical rule determined by experiments. The amount of the lubricant powder is preferably 0.03 to 0.10 wt%. When the amount of the lubricant powder is 0.03 wt%, the best lubricating effect can be ensured during molding of the primary green compact 110. When the amount of the lubricant powder is 0.10 wt%, the desired compression ratio can be obtained when forming the primary green compact 110 from the mixed powder 100. These values were employed in each example.

[0041] The first press molding device 20 is a means that applies the first pressure P1 to the mixed powder 100 with which the first die 21 has been filled using the mixed powder feeding device 10, to form the primary green compact 110. In the first embodiment, the first press molding device 20 has a press structure.

[0042] As illustrated in FIG. 2, the die includes the lower die 21 that is secured on a bolster, and the upper die 25 that is secured on a slide 5. The cavity 22 of the lower die 21 has a shape (cylindrical shape) corresponding to the shape (ring-like shape) of the primary green compact 110. The upper die 25 can be pushed into the lower die 21 (22), and is moved upward and downward using the slide 5. A movable member 23 is fitted into the lower side of the cavity 22 so that the movable member 23 can move in the vertical direction.

[0043] The movable member 23 is moved upward using a knockout pin (not illustrated in the drawings) that moves upward through a through-hole 24 that is formed under a ground level GL. The primary green compact

110 in the die (21 (22)) can thus be moved upward to a transfer level HL. The movable member 23 functions as a first ejection means for ejecting the primary green compact 110 in the die (21 (22)) to the outside (transfer level HL). The movable member 23 and the knockout pin are returned to the initial position after the primary green compact 110 has been transferred to the heating device 30. Note that the first ejection means may be implemented using another means.

[0044] The relationship between the pressure P (first pressure P1) applied by the first press molding device 20 and the density rho of the resulting primary green compact 110 is described below with reference to FIG. 4. The horizontal axis indicates the pressure P using an index. In the first embodiment, the maximum capacity (pressure P) is 10 tons/cm^2 (horizontal axis index: 100). Reference sign Pb indicates the die breakage pressure at which the horizontal axis index is 140 (14 tons/cm^2). The vertical axis indicates the density rho using an index. A vertical axis index of 100 corresponds to a density rho of 7.6 g/cm^3.

[0045] A vertical axis index of 102 corresponds to a density rho of 7.75 g/cm^3. A vertical axis index of 92 corresponds to a density rho of 7.0 g/cm^3, and a vertical axis index of 98 corresponds to a density rho of 7.5 g/cm^3.

[0046] The density rho achieved by the first press molding device 20 increases along the curve indicated by the broken line A as the first pressure P1 increases. The density rho reaches 7.6 g/cm^3 when the horizontal axis index (first pressure is P1) is 100. The density rho increases to only a small extent even if the first pressure P1 is further increased. The die may break if the first pressure P1 is further increased.

[0047] When the density rho achieved by compression at the maximum capacity of the press molding device (press) is not satisfactory, it has been necessary to provide a larger press. However, the density rho increases to only a small extent even if the maximum capacity is increased by a factor of 1.5, for example. Therefore, it has been necessary to accept a low density rho (e.g., 7.5 g/cm^3) when using an existing press.

[0048] It is possible to achieve a major breakthrough if the vertical axis index can be increased from 100 (7.6 g/cm^3) to 102 (7.75 g/cm^3) by directly utilizing an existing press. Specifically, mechanical strength can be significantly improved by improving the density rho by 2%.

[0049] In order to achieve the above breakthrough, the high-strength sintered compact production system 1 is configured so that the primary green compact 110 formed by the first press molding device 20 is heated to promote melting (liquefaction) of the lubricant, and the second press molding device 40 then performs the second press molding process. A high density (7.75 g/cm^3) that corresponds to a vertical axis index of 102 can be achieved (see the solid line B in FIG 4) by applying pressure to the primary green compact 110 using the second press molding device 40. The details thereof are described later in connection with the second press molding device 40.

[0050] The heating device 30 is a means that heats the primary green compact 110 removed from the first die 21 to the melting point of the lubricant powder (i.e., increases the temperature of the primary green compact 110 to the melting point of the lubricant powder). As illustrated in FIG 2, the heating device 30 includes a hot air generator (not illustrated in FIG 2), a blow hood 31, an exhaust/circulation hood 33, and the like. The heating device 30 blows hot air against the primary green compact 110 that is positioned using a wire-mesh holding member 32 to heat the primary green compact 110 to the melting point (120°C) of the lubricant powder. Zinc stearate used in each example has a melting point of 120°C.

[0051] The technical significance of the above low-temperature heat treatment is described below in connection with the relationship with the first press molding step (process). The powder mixture 100 with which the lower die 21 (22) is filled has an area in which the lubricant powder is relatively thinly present (thin area), and an area in which the lubricant powder is relatively densely present (dense area) in connection with the basic metal powder. The inter-particle friction resistance of the basic metal powder, and the friction resistance between the basic metal powder and the inner side of the die are small in the dense area. In contrast, the inter-particle friction resistance of the basic metal powder, and the friction resistance between the basic metal powder and the inner side of the die increase in the thin area.

[0052] When the first press molding device 20 applies pressure to the mixed powder, compressibility is predominant (i.e., compression easily occurs) in the dense area due to low friction. In contrast, compressibility is poor (i.e., compression slowly occurs) in the thin area due to high friction. Therefore, a compression difficulty phenomenon corresponding to the preset first pressure P1 occurs (i.e., compressed limit). In this case, when the fracture surface of the primary green compact 110 removed from the die 21 is magnified, the basic metal powder is integrally pressure-welded in the dense area. However, the lubricant powder is also present in the dense area. In the thin area, small spaces (pores) remain in the pressure-welded basic metal powder, and almost no lubricant powder is observed in the thin area.

[0053] Therefore, it is possible to form compressible spaces by removing the lubricant powder from the dense area, and improve the compressibility of the thin area by supplying the lubricant to the spaces formed in the thin area.

[0054] Specifically, the lubricant powder is melted (liquefied), and increased in fluidity by heating the primary green compact 110 subjected to the first press molding step to the melting point (120°C) of the lubricant powder. The lubricant that flows out from the dense area penetrates through the peripheral area, and is supplied to the thin area. This makes it possible to reduce the inter- particle friction resistance of the basic metal powder, and compress the spaces (pores) that have been occupied by the lubricant powder. It is also possible to reduce the friction resistance between the basic metal powder and the inner side of the die.

[0055] It is particularly worth noting that the technical idea of the invention completely differs from that of the related-art method (e.g., Patent Documents 5 and 7).

[0056] When using a related-art method that considers the green compact molding process to be a preliminary process for the sintering process, a preliminary compact (corresponding to the primary green compact 110) is heated (i.e., strain is removed) at a high temperature (500 to 1000°C). It is considered that the above heat treatment causes a deterioration in quality of the green compact, and prevents an improvement in strength.

[0057] It was found by experiments that the lubricant is melted when the green compact is heated within a low temperature range (500 to 700°C) in the above temperature range (500 to 1000°C). The lubricant is solidified when the green compact is allowed to cool to room temperature to bond the metal particles. As a result, a large number of solidified grains of the lubricant (residue) (waste 108) remain in the pores and the space between the metal particles (101) (see FIG 8A).

[0058] When the green compact is heated within a high temperature range (700 to 1000°C) in the above temperature range (500 to 1000°C), the lubricant is melted and vaporized as the temperature increases. Therefore, the number (amount) of solidified grains (108) tends to decrease. However, diffusion occurs at the contact surface between the metal particles (101), and sintering proceeds at some of the grain boundaries. For example, when using an iron powder, diffusion occurs at the contact surface between the metal particles when heated at 750 to 760°C. Specifically, when the green compact is heated at a high temperature, the pores 109 remain due to vaporization of the lubricant, and a partial sintered area (partial diffusion bond (coupling)) 128 occurs between the metal powder particles (see FIG. 8B) .

[0059] Therefore, when the green compact that has been heated at a low temperature is subjected to the compression process (room- temperature pressing process), a residue cannot be discharged from the green compact, and the waste (e.g., residue) 108 remains in the green compact (see FIG 8A) . When the green compact that has been heated at a high temperature is subjected to the press molding process, the amount of the waste (e.g., residue) 108 is small as compared with the case where the green compact is heated at a low temperature. However, since the partial sintered area 128 occurs at the grain boundaries (see FIG 8B), the number of the pores 109 is reduced by destroying the partial sintered area 128 to increase the density of the compact. When the partial sintered area 128 is present, a very high pressure is required for the second press molding process, and an increase in density of the green compact is limited taking account of the strength of the die. Therefore, when the green compact is heated at a high temperature (500 to 1000°C), the compact obtained by the second press molding process is very fragile, and exhibits low mechanical strength. Moreover, since a high pressure is required for the second press molding process, a press having a high press capacity and a die having high pressure resistance are required. This is very disadvantageous from the viewpoint of the equipment cost.

[0060] According to the first embodiment of the invention, the green compact is heated to the melting point of the lubricant, and the second press molding process is performed on the green compact 110 that is maintained at the melting point of the lubricant. Carbonization does not occur in the green compact 110 that is maintained at the melting point of the lubricant, and the lubricant is melted and can flow. When the press molding process is performed in this stated using a press or the like, the lubricant that has been melted and present in the green compact 110 is discharged from the green compact 110. As a result, only a small amount of the waste (e.g., residue) 108 remains in the green compact (secondary green compact 115) obtained by the press molding process (see FIG 5). Specifically, the green compact 115 that exhibits very high density and high mechanical strength can be produced.

[0061] The second press molding device 40 includes the second die 41 that can be pre-heated in advance to the melting point of the lubricant powder. The second press molding device 40 is a means that applies the second pressure P2 to the heated primary green compact 110 that is placed in the per-heated second die 41 to form the densified secondary green compact 115.

[0062] In the first embodiment, the maximum capacity (pressure P) of the second press molding device 40 is the same as that (10 tons/cm^2) of the first press molding device 20. The first press molding device 20 and the second press molding device 40 are configured as a single press, and the upper die 25 and the upper die 45 can be moved upward and downward in synchronization using the common slide 5 illustrated in FIG. 2. The above configuration is economical, and can reduce the production cost of the secondary green compact 115.

[0063] It suffices that the second pressure P2 be equal to or higher than the first pressure. For example, the first press molding device 20 and the second press molding device 40 may be implemented using two presses so that the maximum capacity (pressure P) of the second press molding device 40 differs from the maximum capacity (pressure P) of the first press molding device 20.

[0064] As illustrated in FIG 2, the die includes the lower die 41 that is secured on a bolster, and the upper die 45 that is secured on the slide 5. The lower part of a cavity 42 of the lower die 41 has a shape (cylindrical shape) corresponding to the shape (ring-like shape) of the secondary green compact 115, and the upper part of the cavity 42 has a slightly larger shape so that the primary green compact 110 can be received. The upper die 45 can be pushed into the lower die 41 (42), and is moved upward and downward using the slide 5. A movable member 43 is fitted into the lower side of the cavity 42 so that the movable member 43 can move in the vertical direction. Note that the die (41) and the die (21) are adjusted in height (position) corresponding to the vertical difference in dimensions between the compression targets (110 and 115).

[0065] The movable member 43 is moved upward using a knockout pin (not illustrated in the drawings) that moves upward through a through-hole 44 that is formed under the ground level GL. The secondary green compact 115 in the second die (41 (42)) can thus be moved upward to the transfer level HL. The movable member 43 functions as a second ejection means for ejecting the secondary green compact 115 in the die (41 (42)) to the outside (transfer level HL). Note that the second ejection means may be implemented using another means. The movable member 43 and the knockout pin are returned to the initial position after the secondary green compact 115 has been discharged to a discharge chute 59, and a new primary green compact 110 has been received from the heating device 30.

[0066] The second die (41 (42)) is provided with a pre-heating means 47 that can be changed in heating temperature. The pre- heating means 47 heats (pre- heats) the second die (41 (42)) to the melting point (120°C) of the lubricant powder (zinc stearate) before the primary green compact 110 is received (placed) . Therefore, the primary green compact 110 that has been heated can be received without allowing the primary green compact 110 to cool. This makes it possible to ensure a lubricating effect while preventing a situation in which the lubricant that has been melted (liquefied) is solidified again.

[0067] The pre-heating means 47 can be heated until the time when the secondary green compact 115 can be press-molded. Therefore, the fluidity of the melted lubricant in all directions during press molding can be further improved, and the friction resistance between the particles and the die 41 (42) can be significantly reduced.

[0068] Note that the pre-heating means 47 may be implemented by a hot oil or hot water circulation system or the like instead of an electric heating system.

[0069] The relationship between the pressure (second pressure P1) applied by the second press molding device 40 and the density rho of the resulting secondary green compact 115 is described below with reference to FIG 4.

[0070] The density rho achieved by the second press molding device 40 is indicated by the straight line that is indicated by the solid line B. Specifically, the density rho does not gradually increase as the second pressure P2 increases, differing from the case of using the first press molding device 20 (see the broken line A). More specifically, the density rho does not increase until the final first pressure P1 (e.g., horizontal axis index: 50, 75, or 85) during the first press molding step is exceeded. The density rho increases rapidly when the second pressure P2 has exceeded the final first pressure P1. This means that the second press molding step is performed continuously with the first press molding step.

[0071] Therefore, the first press molding step need not be performed in a state in which the first pressure P1 is necessarily increased to a value (horizontal axis index: 100) corresponding to the maximum capacity. This makes it possible to prevent unnecessary time and energy consumption that may occur when the first press molding step is continued after the compressed limit has been reached. Therefore, the production cost can be reduced. Moreover, since it is possible to avoid overloaded operation in which the horizontal axis index exceeds 100, breakage of the die does not occur. This makes it possible to ensure easy and stable operation.

[0072] In each example, the molding process was performed in a state in which the first pressure P1 was selected to be a pressure (vertical axis index: 92 to 98) that can increase the density rho to 7.0 to 7.5 g/cm^3. The upper-limit value 7.5 g/cm^3 (vertical axis index: 98) is selected so that the vertical axis index does not exceed 100 (critical region), and the lower-limit value 7.0 g/cm^3 (vertical axis index: 92) is selected so that a margin is provided between the upper-limit value and the lower-limit value. This aims at facilitating handling (e.g., pressure setting) and operation. The second pressure P2 is selected to correspond to a vertical axis index of 92 (98) to 100 so that the secondary green compact 115 having a density rho (7.75 g/cm^3) corresponding to a vertical axis index of 102 can be produced. In Example 2, the density is indicated by the true density ratio taking account of the mixing ratio.

[0073] As illustrated in FIG. 2, the sintering device 80 is implemented by a continuous sintering furnace, and is configured so that the secondary green compact 115 introduced through the chute 59 can be sintered at a given temperature for a given time while continuously moving the secondary green compact 115 at low speed using a conveyer (not illustrated in FIG 2). A plurality of secondary green compacts 115 can be efficiently and uniformly sintered using the sintering device 80. Specifically, it is possible to produce the sintered compact 120 that exhibits improved strength. Note that the sintering device 80 is omitted in FIGS. 3A and 3B. The sintering device 80 may be implemented by a batch-type sintering furnace.

[0074] The sintering temperature is normally about 1120°C when using an iron powder, and is about 1250°C when implementing a high-temperature sintering process. Since sintering proceeds even when increasing the temperature, the holding time at the maximum temperature may be about 30 minutes. In the first embodiment, the sintering temperature and the sintering time (conveyer speed) can be set variably.

[0075] Since only a small amount of the waste (e.g., residue) 108 is present in the secondary green compact 115 (i.e., the secondary green compact 115 has high density) (see FIG. 5), the contact area between the metal particles (101) is large. This means that a diffusion bond (diffusion coupling) having the same area as that achieved by a related-art method can be obtained by a short sintering time as compared with a related-art method. Specifically, since a diffusion bond can be formed over a wider area due to an increase in contact area, the mechanical characteristics (strength) can be significantly improved.

[0076] Moreover, since the internal (strain) stress can be removed by the final sintering process, it is unnecessary to perform an annealing process.

[0077] As illustrated in FIG. 3B, a workpiece transfer means 50 can transfer the primary green compact 110 removed from the first die 21 using the first ejection means (23, 24) (see FIG 3A) to a given position in the heating device 30, can transfer the heated primary green compact 110 from the given position in the heating device 30 to the second die 41, and can transfer the secondary green compact 115 removed from the second die 41 using the second ejection means (43, 44) to the discharge chute 59.

[0078] In the first embodiment, the workpiece transfer means 50 is formed by three transfer bars 51, 52, and 53 (see FIG. 3B) that are operated in synchronization. The transfer bars 51, 52, and 53 are moved to the front transfer line (FIG 3B) from the deep side in FIG 3A when a transfer request has been issued, moved from left to right, and then returned to the original position. A placement means (52, 43, 44) places the heated primary green compact 110 in the second die 42 that is pre-heated to the melting point of the lubricant powder.

[0079] Note that the workpiece transfer means may be implemented by a transfer device that includes a finger that is driven in two-dimensional or three-dimensional directions, and the like, and sequentially transfers a workpiece to each die or the like. The workpiece transfer means may be formed so that the secondary green compact 115 can be transferred to the sintering device 80.

[0080] The high-strength sintered compact (120) production system 1 according to the first embodiment implements the method for producing a high-strength sintered compact as described below.

Preparation of mixed powder

[0081] The basic metal powder and the lubricant powder (zinc stearate powder) (0.03 to 0.10 wt%) are mixed to prepare the mixed powder 100 in a dry state. A given amount of the mixed powder 100 is supplied to the mixed powder feeding device 10 (step PR0 in FIG. 1).

Filling with mixed powder

[0082] The mixed powder feeding device 10 is moved from a given position (indicated by the solid line in FIG 3B) to a supply position (indicated by the dotted line in FIG 3B) at a given timing. The inlet of the mixed powder feeding device 10 is then opened, and the empty lower die 21 (22) of the first press molding device 20 is filled with the mixed powder 100 (step PR1 in FIG 1). The lower die 21 (22) can be filled with the mixed powder 100 within 2 seconds, for example. The inlet is closed after the lower die 21 (22) has been filled with the mixed powder 100, and the mixed powder feeding device 10 is returned to the given position (indicated by the solid line in FIG 3B).

Forming of primary green compact

[0083] The upper die 25 of the first press molding device 20 is moved downward using the slide 5 illustrated in FIG 2, and applies the first pressure P1 to the mixed powder 100 in the lower die 21 (22) (first press molding process). The solid lubricant produces a sufficient lubricating effect. The density rho of the compressed primary green compact 110 increases along the broken line A in FIG 4. When the first pressure P1 has reached a pressure (9.5 tons/cm^2) corresponding to a horizontal axis index of 95, for example, the density rho increases to 7.25 g/cm^3 (vertical axis index: 95). The press molding process is performed for 8 seconds, for example, to obtain the primary green compact 110 that has been molded in the die (21) (see FIG 3A) (step PR2 in FIG 1). The upper die 25 is then moved upward using the slide 5. Note that the second press molding process on the preceding primary green compact 110 is performed in the second press molding device 40 in synchronization with the above operation.

Removal of primary green compact

[0084] The first ejection means (23) moves the primary green compact 110 upward to the transfer level HL. Specifically, the primary green compact 110 is removed from the lower die 21. The workpiece transfer means 50 then transfers the primary green compact 110 to the heating device 30 using the transfer bar 51 (see FIG 3B), and the movable member 23 is returned to the initial position. The primary green compact 110 that has been transferred to the heating device 30 is positioned on the wire-mesh holding member (32) (see FIG 3A).

Heating

[0085] The heating device 30 starts to operate (see FIG 3A). Hot air is blown against the primary green compact 110 from the blow hood 31, so that the primary green compact 110 is heated to the melting point (120°C) of the lubricant powder (step PR3 in FIG 1). Specifically, the lubricant is melted, and the distribution of the lubricant in the primary green compact 110 becomes uniform. The heating time is 8 to 10 seconds, for example. Note that the hot air is recycled through the wire-mesh holding member 32 and the exhaust/circulation hood 33.

Placement of heated primary green compact

[0086] The heated primary green compact 110 is transferred to the second press molding device 40 by the workpiece transfer means 50 (transfer bar 52) (see FIG 3B), positioned over the lower die 41, and placed on the movable member 43 in the lower die 41 (42) (step PR4 in FIG. 1).

Pre-heating of die

[0087] The pre-heating means 47 of the second press molding device 40 heats the die (41 (42)) to the melting point (120°C) of the lubricant powder before the primary green compact 110 is received (placed). This makes it possible to prevent solidification of the lubricant in the primary green compact 110 that has been received.

Molding of secondary green compact

[0088] The upper die 45 is moved downward using the slide 5 illustrated in FIG 2 (see FIG. 3A), and applies the second pressure P2 to the primary green compact 110 in the lower die 41 (42). The liquid lubricant produces a sufficient lubricating effect. Since the lubricant flows in all directions during the press molding process, the friction resistance between the particles and the die can be efficiently reduced. The density rho of the compressed primary green compact 110 increases along the broken line B in FIG 4. Specifically, when the second pressure P2 has exceeded a horizontal axis index of 95 (9.5 ton/cm^2), for example, the density rho rapidly increases from 7.25 g/cm^3 to a value (7.75 g/cm^3) corresponding to a vertical axis index of 102. When the second pressure P2 is increased to a horizontal axis index of 100 (10 tons/cm^2), the density rho (7.75 g/cm^3) becomes uniform over the entire green compact. The second press molding process is performed for 8 seconds, for example, to obtain the secondary green compact 115 that has been molded in the die (41) (step PR5 in FIG 1). The upper die 45 is then moved upward using the slide 5. Note that the first press molding process on the subsequent primary green compact 110 is performed in the first press molding device 20 in synchronization with the above operation.

Removal of secondary green compact

[0089] The second ejection means (43) moves the secondary green compact 115 upward to the transfer level HL. Specifically, the secondary green compact 115 is removed from the lower die 41. The workpiece transfer means 50 then transfers the secondary green compact 115 to the discharge chute 59 using the transfer bar 53 (see FIG 3B), and the movable member 43 is returned to the initial position.

Forming cycle

[0090] According to the above molding method that includes the two molding steps, since the first press molding process, the heating process, and the second press molding process can be performed on the sequentially supplied metal powder 100 in synchronization, the secondary green compact 115 can be produced in a cycle time of 12 to 14 seconds (i.e., maximum heating time (10 seconds) + workpiece transfer time (e.g., 2 to 4 seconds)).

Forming of sintered compact

[0091] The secondary green compact 115 introduced from the discharge chute 59 is sintered by the sintering device 80. The green compact 115 illustrated in FIG 5 forms the sintered compact 120 that exhibits improved strength via sintering. It is thus possible to ensure stable supply of the sintered compact 120 (e.g., automotive parts or mechanical (equipment) parts that have a reduced size and weight, a complex shape, and high mechanical strength), and significantly reduce the production cost.

Example 1

[0092] A basic metal powder (pure iron powder for mechanical parts) and a lubricant powder (zinc stearate powder) (0.03 to 0.10 wt%) were mixed to prepare a mixed powder 100. The mixed powder 100 was press-molded by applying the first pressure P1 to form a primary green compact 110 having a density of 7.0 to 7.5 g/cm^3. The first press molding step could be performed most smoothly when the amount of the lubricant powder was 0.03 wt%. The primary green compact 110 was heated to 120°C, and press-molded by applying the second pressure P2 to form a secondary green compact 115 having a density rho of 7.75 g/cm^3 (vertical axis index: 102). The secondary green compact 115 was sintered at 1150°C for 30 minutes to obtain a sintered compact 120 exhibiting improved mechanical strength. Mechanical strength (e.g., tensile force) increases corresponding to density. Specifically, since the density could be increased by the second press molding step (performed before the sintering process) as compared with the related-art method, a mechanical part exhibiting improved mechanical strength could be efficiently produced by performing the sintering process. It was also confirmed that a similar product could be obtained when mixing the basic metal powder with an alloy-forming metal powder. Therefore, high strength can be achieved even when producing an elongated cylindrical shape as illustrated in FIG. 6B.

Example 2

[0093] A basic metal powder (Fe-Si alloy powder) and a lubricant powder (zinc stearate powder) (0.03 to 0.10 wt%) were mixed to prepare a mixed powder 100. The mixed powder 100 was press-molded by applying the first pressure P1 to form an primary green compact 110 having a true density ratio of 70 to 85%. The first press molding step could be performed most smoothly when the amount of the lubricant powder was 0.03 wt%. The primary green compact 110 was heated to 120°C, and press-molded by applying the second pressure P2 to form a secondary green compact 115 having a true density ratio of 80% (vertical axis index: 102). The secondary green compact 115 was sintered at 1150°C for 30 minutes to obtain a sintered compact 120 exhibiting improved mechanical strength. A sintered compact exhibiting high mechanical strength as compared with a sintered compact formed by the related-art method could thus be efficiently produced.

[0094] Since the method for producing a high-strength sintered compact according to the first embodiment includes applying the first pressure P1 to the mixed powder 100 in the first die at room temperature that is less than the melting point of the lubricant powder to form the primary green compact 110 (first press molding step), heating the primary green compact 110 to the melting point of the lubricant powder (heating step), applying the second pressure P2 to the primary green compact 110 in the second die (pre-heated to the melting point of the lubricant powder) at the melting point of the lubricant powder to form the densified secondary green compact 115, and sintering step the secondary green compact 115 to form a sintered compact, the high-strength sintered compact 120 can be reliably and stably produced while significantly reducing the production cost.

[0095] Since the lubricant powder has a low melting point within the range of 90 to 190°C, various types of lubricant can be selected while suppressing oxidation.

[0096] The method according to the first embodiment can efficiently and stably produce a sintered compact 120 that exhibits high excellent mechanical strength corresponding to the type of the basic metal powder, using a pure iron powder or an Fe-Si alloy powder as the basic metal powder.

[0097] Since the second pressure P1 can be made equal to the first pressure P, it is possible to easily implement the press molding step, facilitate handling, indirectly reduce the green compact production cost, and easily implement the system based on a single press, for example.

[0098] It has been impossible to achieve a density equal to or higher than that corresponding to a vertical axis index of 100, taking account of the capacity (horizontal axis index=100 (see FIG 4)) of a related-art system (e.g., press). According to the first embodiment, however, it is possible to achieve a density equal to or higher than that corresponding to a vertical axis index of 102 using an identical (existing) system. This fact achieves a major breakthrough in the technical field.

[0099] Moreover, the production system 1 that includes the mixed powder feeding device 10, the first press molding device 20, the heating device 30, the second press molding device 40, and the sintering device 80 can reliably and stably implement the method for producing the high- strength sintered compact 120.

Second embodiment

[0100] FIG 7 illustrates a second embodiment of the invention. The second embodiment is identical with the first embodiment as to the mixed powder feeding device 10, the first press molding device 20, and the sintering device 80, but differs from the first embodiment in that the heating device 30 and the second press molding device 40 are integrally formed.

[0101] Specifically, a production system 1 according to the second embodiment includes a heating/ press molding device 70 that has the function of the heating device 30 and the function of the second press molding device 40 (see the first embodiment) . The heating/ press molding device 70 includes a plurality of (e.g., two) heating/ press molding sub- devices 70A and 70B. The heating/ press molding sub- devices 70A and 70B are selectively (sequentially) operated by a control means (not illustrated in the drawings) in a production cycle.

[0102] Each heating/press molding sub-device 70A (70B) has a basic structure similar to that of the second press molding device 40 described above in connection with the first embodiment. Each heating/press molding sub-device 70A (70B) includes a hybrid heating means 48 having the functions of the heating device 30 and the pre-heating means 47 described above in connection with the first embodiment.

[0103] Specifically, the hybrid heating means 48 is an electric heating means having a present temperature change function. The hybrid heating means 48 can preheat the lower die 41 to the melting point (120°C) of the lubricant in advance (i.e., before the primary green compact 110 is received) . When the primary green compact 110 has been received, the amount of heat is changed so that the entire primary green compact 110 can be heated to the melting point (120°C) of the lubricant. The heating target area can also be selected (changed) . After completion of the above heating process, the second press molding process is performed using the second press molding device 40 in the same manner as in the first embodiment. The hybrid heating means 48 can maintain the primary green compact 110 at a temperature equal to or higher than the melting point (120°C) of the lubricant during the second press molding process.

[0104] As illustrated in FIG. 7, each heating/press molding sub-device (20, 70A, 70B) has an independent press structure, and each slide (5, 5A, 5B) is independently moved upward and downward by controlling the rotation of each motor. Specifically, when one of the heating/press molding sub-devices 70A and 70B performs press molding operation, the other of the heating/press molding sub-devices 70A and 70B performs preheating operation, and does not perform press molding operation. This also applies to the case where the heating/ press molding device 70 is implemented by three or more heating/press molding sub-devices taking account of the production cycle time.

[0105] In the second embodiment, when the third intermediate green compact 110 is press-molded in the first press molding device 20, the second primary green compact 110 is heated by the heating/press molding sub-device 70A (or 70B), and the first primary green compact 110 is press-molded by the heating/press molding sub-device 70B (or 70A) to form the secondary green compact 115. The sintering device 80 sinters a plurality of secondary green compacts 115 during this period to form a plurality of sintered compacts 120.

[0106] According to the second embodiment, since the heating/press molding device 70 is implemented by a plurality of heating/press molding sub-devices 70A and 70B having an identical structure, the system can be simplified as compared with the first embodiment. It is also possible to simplify the production line, and further facilitate handling. According to the second embodiment, the takt time of the first press molding step, the heating step, and the second press molding step can be made equal.

[0107] Note that the first press molding device 20 and the heating/press molding sub-device 70A (or 70B), or the first press molding device 20 and the heating/press molding sub-devices 70A and 70B may be implemented by a single press structure.

[0108] Although only some embodiments of the invention have been described in detail above, those skilled in the art would readily appreciate that many modifications are possible in the embodiments without materially departing from the novel teachings and advantages of the invention. Accordingly, all such modifications are intended to be included within the scope of the invention.

REFERENCE SIGNS LIST

[0109] 1: high-strength sintered compact production system, 10: mixed powder feeding device, 20: first press molding device, 30: heating device, 40: second press molding device, 47: pre-heating means, 48: hybrid heating means, 50: workpiece transfer means, 70: heating/press molding device, 70A, 70B: heating/press molding sub-device, 80: sintering device, 100: mixed powder, 101: iron powder, 108: waste (residue), 109: pore, 110: primary green compact, 115: secondary green compact, 120: sintered compact, 128: partial sintered area

Claims

1. A method for producing a high-strength sintered compact comprising:

   a press molding step that applies pressure to a mixed powder to form a green compact, the mixed powder being a mixture of a basic metal powder and a lubricant powder; and
   a sintering step that sinters the green compact to form a sintered compact that exhibits improved mechanical strength,
   the press molding step including a first press molding step and a second press molding step, a heating step being provided between the first press molding step and the second press molding step,
   the first press molding step applying a first pressure to the mixed powder in a first die at room temperature that is less than a melting point of the lubricant powder to form a primary green compact,
   the heating step heating the primary green compact to the melting point of the lubricant powder, and
   the second press molding step applying a second pressure to the primary green compact in a second die at the melting point of the lubricant powder to form a densified secondary green compact, the second die being heated to the melting point of the lubricant powder.

2. The method for producing a high-strength sintered compact as defined in claim 1,
   wherein the lubricant powder has a low melting point within a range of 90 to 190°C.

3. The method for producing a high-strength sintered compact as defmed in claim 1 or 2,
   wherein the mixed powder is prepared by mixing a pure iron powder as the basic metal powder with 0.03 to 0.10 wt% of a zinc stearate powder as the lubricant powder, the first pressure is selected to compress the mixed powder so that the primary green compact has a density of 7.0 to 7.5 g/cm^3, and the second pressure is selected to compress the primary green compact so that the secondary green compact has a density of 7.75 g/cm^3.

4. The method for producing a high-strength sintered compact as defined in claim 1 or 2,
   wherein the mixed powder is prepared by mixing an Fe-Si alloy powder as the basic metal powder with 0.03 to 0.10 wt% of a zinc stearate powder as the lubricant powder, the first pressure is selected to compress the mixed powder so that the primary green compact has a true density ratio of 70 to 85%, and the second pressure is selected to compress the primary green compact so that the secondary green compact has a true density ratio of 85 to 95%.

5. The method for producing a high-strength sintered compact as defined in claim 1 or 2,
   wherein the second pressure is selected to be equal to the first pressure.

6. A high-strength sintered compact production system comprising:

   a mixed powder feeding device that can externally supply a mixed powder that is a mixture of

a basic metal powder and a lubricant powder that has a low melting point;
a first press molding device that applies a first pressure to the mixed powder in a first die to form a primary green compact, the first die being filled with the mixed powder using the mixed powder feeding device;
a heating device that heats the primary green compact removed from the first die to the melting point of the lubricant powder;
a second press molding device that includes a second die that can be pre-heated to the melting point of the lubricant powder in advance, and applies a second pressure to the primary green compact that has been heated and is placed in the pre-heated second die to form a densified secondary green compact; and
a sintering device that sinters the secondary green compact to form a sintered compact that exhibits improved mechanical strength.

7. The high-strength sintered compact production system as defined in claim 6,
wherein the heating device and the second press molding device are formed by a heating/press molding device having a function of the heating device and a function of the second press molding device, the heating/press molding device includes a plurality of heating/press molding sub-devices, and each of the plurality of heating/press molding sub-devices can be selectively and sequentially operated in each cycle.

FIG.1

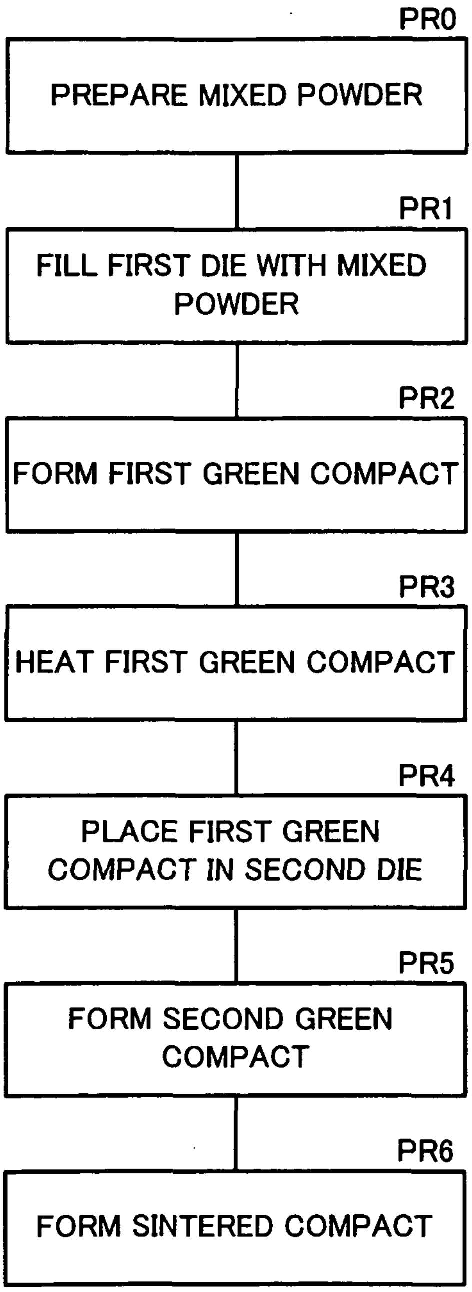

PR0
PREPARE MIXED POWDER
PR1
FILL FIRST DIE WITH MIXED POWDER
PR2
FORM FIRST GREEN COMPACT
PR3
HEAT FIRST GREEN COMPACT
PR4
PLACE FIRST GREEN COMPACT IN SECOND DIE
PR5
FORM SECOND GREEN COMPACT
PR6
FORM SINTERED COMPACT

FIG.2

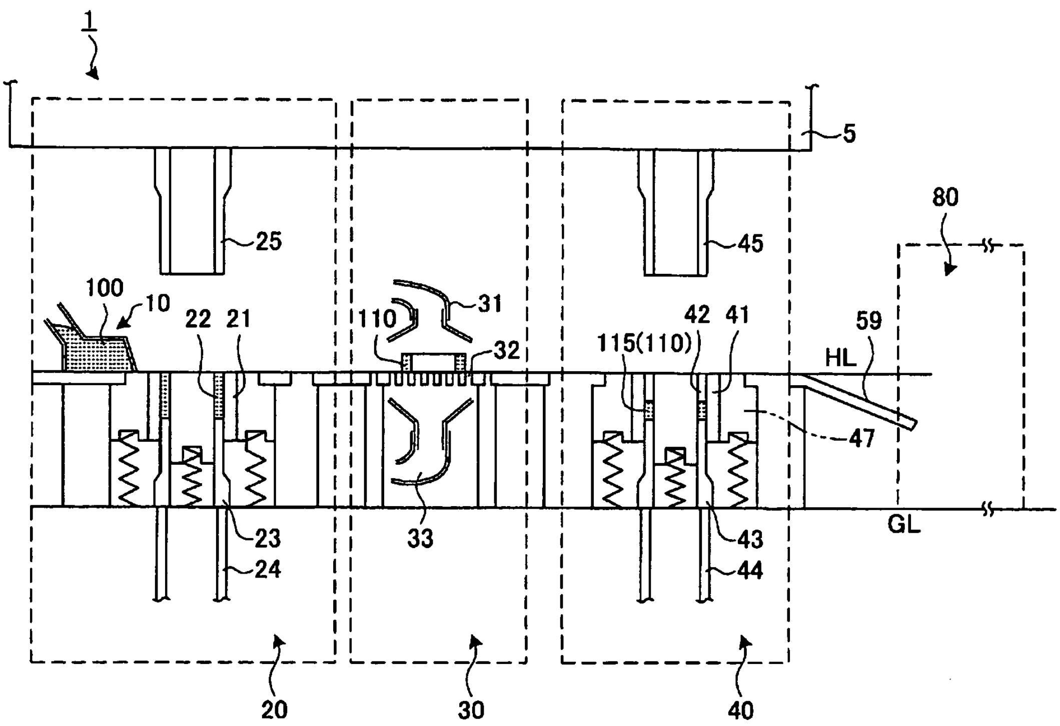

1
5
25
45
80
100
10
22
21
110
31
32
115(110)
42
41
59
HL
47
23
24
33
43
44
GL
20
30
40

FIG.3A

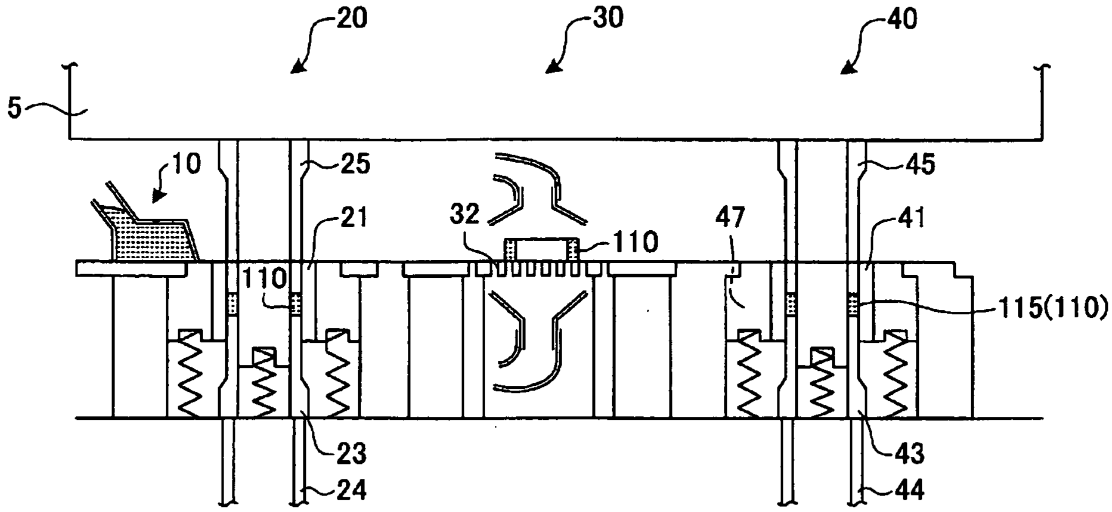

20
30
40
5
10
25
45
21
32
110
47
41
110
115(110)
23
43
24
44

FIG.3B

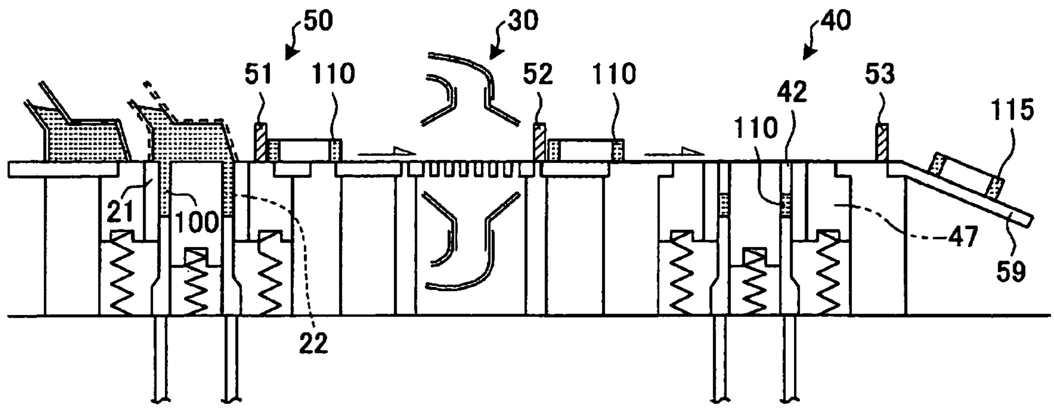

50
30
40
51
110
52
110
53
42
115
110
21
100
47
59
22

FIG.4

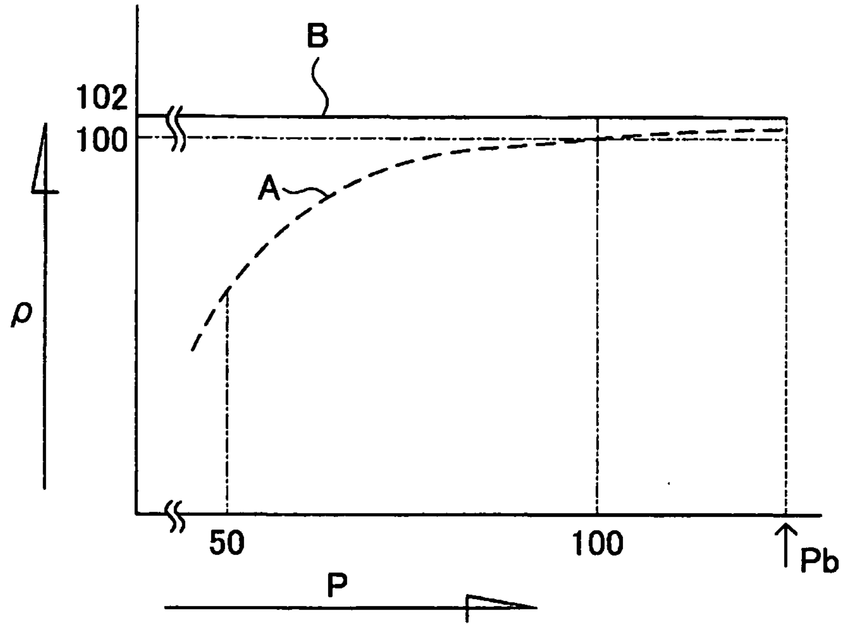


FIG.5

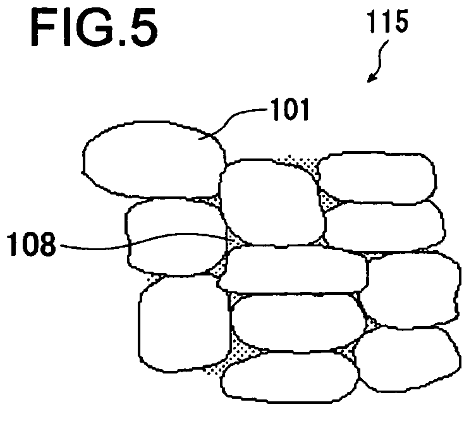


FIG.6A

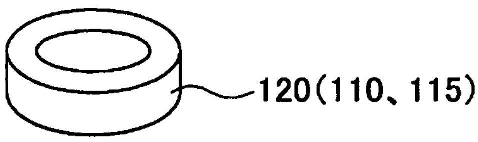


FIG.6B

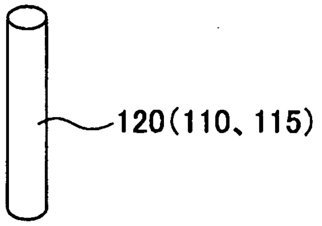

120(110、115)

FIG.7

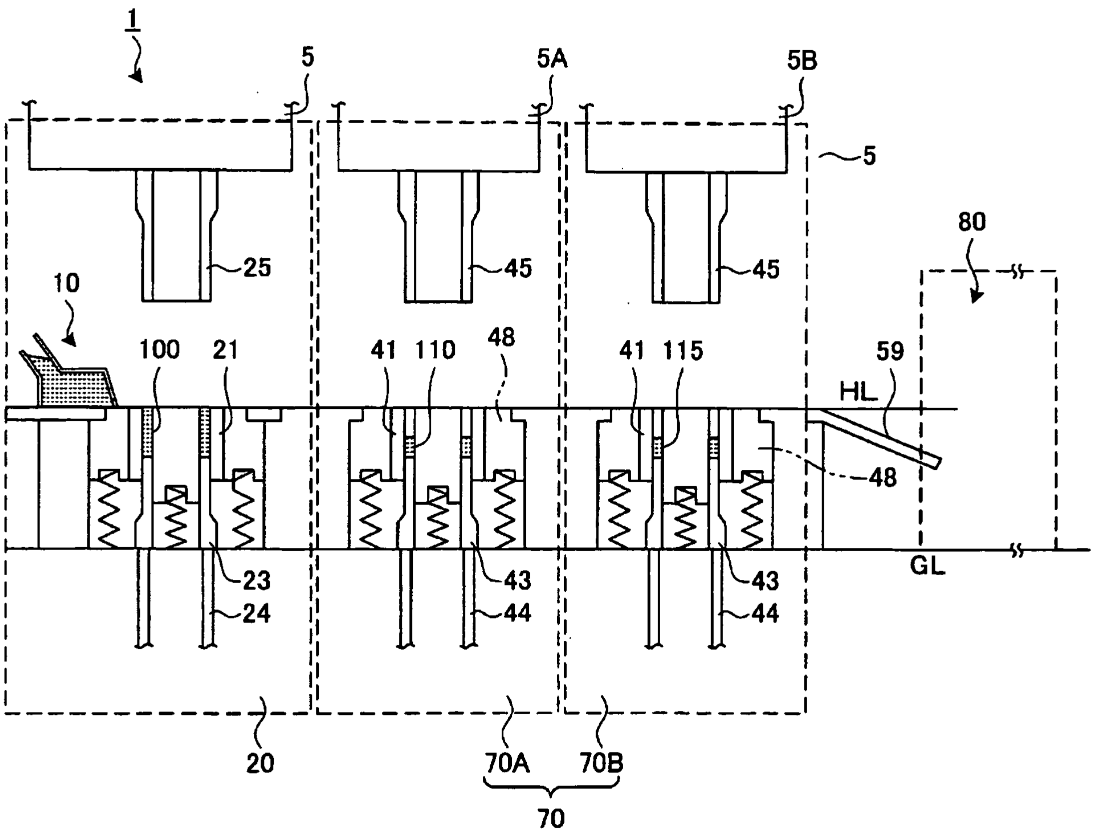

1
5
5A
5B
5
25
45
45
80
10
100
21
41
110
48
41
115
59
HL
48
23
43
43
GL
24
44
44
20
70A
70B
70

FIG.8A

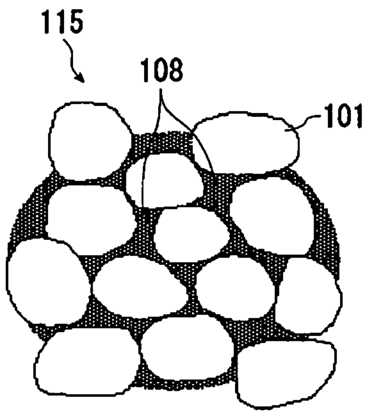
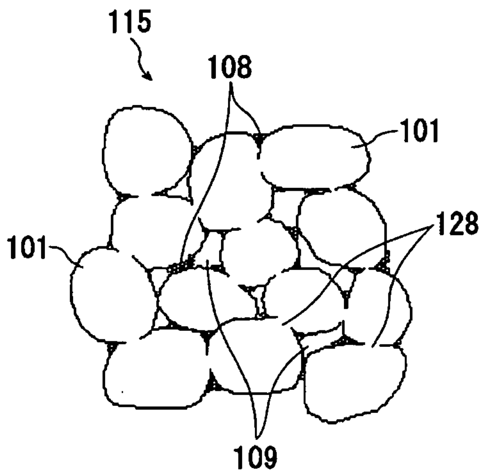


FIG.8B



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/078414

A. CLASSIFICATION OF SUBJECT MATTER
B22F3/02(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)
B22F1/00-8/00, C22C1/04, C22C1/05, C22C33/02

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	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

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 2000-87104 A (Hitachi Powdered Metals Co., Ltd.), 28 March 2000 (28.03.2000), claims; paragraphs [0002], [0004], [0009], [0013], [0016] to [0021] (Family: none)	1-7
X A	JP 11-267893 A (Hitachi Powdered Metals Co., Ltd.), 05 October 1999 (05.10.1999), claims; paragraphs [0011] to [0022] (Family: none)	6,7 1-5

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 February, 2012 (06.02.12)	14 February, 2012 (14.02.12)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/078414

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 2005-526178 A (GKN Sinter Metals GmbH), 02 September 2005 (02.09.2005), claims; paragraph [0009] & US 2005/36899 A1 & EP 1469963 A2 & WO 2003/064083 A2 & DE 10203283 A1 & BR 307194 A & CN 1628008 A & AU 2003239254 A1	1-7
A	JP 2001-252793 A (Hitachi Powdered Metals Co., Ltd.), 18 September 2001 (18.09.2001), claims; paragraph [0015] (Family: none)	1-7
A	JP 61-166903 A (Hitachi Metals, Ltd.), 28 July 1986 (28.07.1986), claims (Family: none)	1-7

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 1219101 A **[0003]**
- JP 2009280908 A **[0004]**
- JP 2010037632 A **[0004]**
- JP 2156002 A **[0005]**
- JP 4231404 A **[0005]**
- JP 2001181701 A **[0005]**
- JP 2002343657 A **[0009]**

Non-patent literature cited in the description

- Autumn Meeting of Japan Society of Powder and Powder Metallurgy. Toyota Central R & D Labs., Inc, 2009 **[0008]**