

SPECIFICATION

MOLDING APPARATUS

【Field of the Invention】

【0001】

The present invention relates to a molding apparatus for manufacturing a molded body by compression-molding a powder and relates, in particular, to a molding apparatus to be used in manufacturing a rare-earth permanent magnet such as a Nd-Fe-B system permanent magnet.

【Background Art】

【0002】

Rare-earth permanent magnets, particularly Nd-Fe-B sintered magnets (so-called neodymium magnet) are made of a combination of iron with elements of Nd and B that are low-priced and abundant as natural resources and also capable of stable supply, and can therefore be manufactured at a low cost and, at the same time, have high magnetic properties (maximum energy product is about 10 times that of ferritic magnets). Therefore, they are used in various kinds of electronic products and are recently widely used in motors and generators for hybrid cars.

【0003】

As an example of manufacturing Nd-Fe-B sintered magnets, there is known a powder metallurgy method. In this method, Nd, Fe and B are first mixed in a predetermined composition ratio, dissolved, and molded to manufacture an alloy raw material. It is once coarsely crushed by, e.g., hydrogen crushing step, and is subsequently finely ground by, e.g., jet mill fine grinding step, thereby obtaining an alloy raw meal powder. Then, the obtained alloy raw meal powder is subjected to orientation in the magnetic field (magnetic field orientation), and is compression-molded while being charged with magnetic field, thereby obtaining a molded body. Then, the

molded body is sintered under predetermined conditions to thereby manufacture a sintered magnet.

【0004】

As a method of compression molding in the magnetic field, there is generally used a uniaxial pressurizing type of compression molding apparatus. In this compression molding apparatus, alloy raw meal powder is filled into a cavity formed in a penetrating hole in a die, and is pressurized (pressed) by a pair of upper and lower punches from the upper and lower directions to thereby form a product out of the alloy raw meal powder. However, at the time of compression molding by means of the pair of punches, high orientation cannot be obtained, and the improvement in the magnetic properties cannot be attained, due to the friction among the particles of the alloy raw meal powder and due to the friction between the alloy raw meal powder and the wall surface of the mold set in position in the punch. In view of the above, there is known another compression molding apparatus in which, after having filled a cavity with alloy raw meal powder, at least one of punches of an upper punch and a lower punch is vibrated in the direction of pressurizing (pressing direction) at the time of magnetic field orientation (see patent document 1).

Patent Document 1: International Publication No. 2002-60677, see e.g., claims)

【Disclosure of the Invention】

【Problems to be Solved by the Invention】

【0005】

However, in the above-described compression molding apparatus, since vibration is caused to take place only by one of the upper punch and the lower punches at the time of magnetic field orientation, the positional relationship among the particles of the alloy raw meal powder within the cavity hardly changes from the state in which it was initially filled into the cavity. As a

result, in case the crystal fractures of the adjoining particles in the orientation direction of the magnetic field do not match with each other (since alloy raw meal powder of Nd-Fe-B sintered magnet is manufactured by mixing Nd, Fe and B and fusing and alloying and thereafter grinding them, the surface of the alloy raw meal powder has formed therein crystal fractures), clearance will remain, in the end, among the particles of the alloy raw meal powder and, therefore, the easy axis of magnetization of the alloy raw meal powder will not be in order. If compression molding is executed in this state, there is a problem in that the orientation will get out of order.

【0006】

In view of the above points, this invention has an object of providing a molding apparatus which is constituted to be able to obtain a molded body of extremely high orientation by arranging such that the crystal fractures of the powder having more equal crystal orientational relationship can be combined together.

【Means for Solving the Problems】

【0007】

In order to solve the above problems, the molding apparatus according to claim 1 comprises: a filling chamber filled with powder that is polarized in one of magnetic field and electric field; means for generating one of magnetic field and electric field so as to enable to charge the powder filled in the filling chamber with one of the magnetic field and electric field; an agitating means for agitating and orienting the powder in a state of being charged with one of the magnetic field and electric field; and a pressurizing means for applying a compression force in one of the magnetic field and electric field to the powder that has been agitated and oriented, thereby molding the powder.

【0008】

According to this invention, since the powder filled in the filling chamber can be agitated and oriented by the agitating means in the magnetic

field or electric field, the positional relationship among the particles of the powder in the filling chamber will be changed from the state in which the powder was initially filled into the filling chamber. As a result, there will be more chances in which, among the combinations of crystal fractures in orienting in the magnetic field or electric field, the crystal fractures having more equal crystal orientational relationship get bonded. Once the crystal fractures having equal crystal orientational relationship are bonded, there will be formed firm bonding chains and, as a result, the crystal fractures get combined and arrayed without clearance in the magnetic field orientation. Then, the powder can be molded by the pressuring means under compression in a state in which the crystal fractures having equal crystal orientational relationship get combined together, there can be obtained a molded body having a high orientation. At the same time, since the crystal fractures having equal orientational relationship are firmly bonded together, there can be obtained a molded body of high density at a lower molding pressure. As a result, the strength of the molded body increases and the rate of occurrence of rejection can be lowered.

【0009】

If the agitating means is the agitating means is disposed in a manner to be movable into and out of the filling chamber, the workability for obtaining the molded body by compression-molding the powder can advantageously be improved.

【0010】

If the filling chamber has an opening for filling the powder therethrough, and a lid body is provided integral with the agitating means in a manner to close the opening when the agitating means is moved into the filling chamber, the powder can be prevented from splashing out of the filling chamber during agitation.

【0011】

If the agitating means is constituted by a non-magnetic material, when, e.g., alloy raw meal powder for a permanent magnet is agitated in the magnetic field, the magnetic field can be prevented from getting disturbed due to adhesion of the alloy raw meal powder to the agitating means and due to consequent insufficient agitation of the alloy raw meal powder.

【0012】

The means for generating the magnetic field shall preferably be capable of generating static magnetic field in a range of magnetic field intensity of 5~30 kOe. When a rare-earth permanent magnet is manufactured, if the intensity of the magnetic field is below 5 kOe, a permanent magnet of high orientation and high magnetic properties cannot be obtained. If the intensity of the magnetic field is above 30 kOe, the magnetic field generating apparatus becomes too large, and the durability of the apparatus becomes poor, which is not practical.

【0013】

On the other hand, the means for generating the magnetic field may be arranged to be capable of generating magnetic pulse field in a range of magnetic field intensity of 5~50 kOe. According to this configuration, it is possible to cause the powder itself that has been filled in the filling chamber to be vibrated, thereby further improving the orientation. However, if the intensity of the magnetic field is below 5 kOe, there cannot be obtained a permanent magnet having high orientation and high magnetic properties. If the intensity of the magnetic field is above 50 kOe, the magnetic field generating apparatus becomes too large, and the durability of the apparatus becomes poor, which is not practical.

【0014】

The above-described powder is alloy raw meal powder for rare-earth magnet and the alloy raw meal powder is manufactured by quenching method. According to this configuration, the alloy raw meal powder becomes

angular particulate shape, whereby the area of a single crystal fracture can be made large and the clearance among the particles of the alloy raw meal powder can be made small. By thus improving the flowability of the alloy raw meal powder, the chances become further increased in which the crystal fractures of the alloy raw meal powder having more equal crystal orientational relationship get combined with one another. In addition thereto, the orientation can further be improved. As a result, by using the molding apparatus of this invention, there can be obtained a permanent magnet that is high in density without disturbance in orientation and that is high in magnetic properties.

【Effect of the Invention】

【0015】

As described hereinabove, according to the molding apparatus of this invention, there can be obtained an effect in that crystal fractures of the powder having more equal crystal orientational relationship in the magnetic field or in the electric field are arranged to get combined, thereby manufacturing a molded body of an extremely high orientation.

【Best Mode for Carrying out the Invention】

【0016】

With reference to FIGS. 1 through 5, reference numeral 1 denotes a molding apparatus according to this invention. The molding apparatus 1 is suitable for manufacturing rare earth permanent magnet, in particular, Nd-Fe-B sintered magnet (inclusive of oriented body and molded body). The molding apparatus 1 is a compression molding apparatus of a uniaxial pressurizing type in which the direction of pressurizing (pressing direction) is vertical to the direction of magnetic orientation, and has a base plate 12 which is supported by leg pieces 11. Above the base plate 12 there is disposed a die 2. The die 2 is supported by a plurality of supporting columns 13 which penetrate through the base plate 12. The other end of each of the

supporting columns 13 is connected to a connecting plate 14 disposed below the base plate 12. The connecting plate 14 is connected to a driving means, e.g., a cylinder rod 15 of a hydraulic cylinder of a known construction. According to this configuration, when the lower hydraulic cylinder is actuated to move up and down the connection plate 14, the die 2 is movable in an up-and-down direction (pressurizing direction Y).

【0017】

In substantially the central part of the die 2, there is formed a penetrating hole 21 in the up-and-down direction. Into the penetrating hole 21 there can be inserted a lower punch 31 which is vertically disposed on substantially the central part of the upper surface of the base plate 12. When the lower hydraulic cylinder is actuated to lower the die 2, the lower punch 31 is inserted into the penetrating hole 21 to thereby define a cavity (filling chamber) 22 inside the penetrating hole 21. Relative to the cavity 22 a powder feeding apparatus (not illustrated) of the known construction is movable back and forth. By means of this powder feeding apparatus there can be filled an alloy raw meal powder metered in advance into the cavity 22.

【0018】

On an upper part of the die 2 there is disposed a die base 16 which lies opposite to the base plate 12. On a lower surface of the die base 16 there is provided an upper punch 32 in a position capable of insertion into the cavity 22. A vertically disposed pair of the upper punch 32 and the lower punch 31 constitutes the pressuring means. Further, at the corner portions of the die base 16 there are formed penetrating holes in the vertical direction. In each of the penetrating holes there is inserted a guide rod 17 one end of which is fixed to the upper surface of the die 2. To the upper surface of the die base 16 there is connected a driving means, e.g., a cylinder rod 18 of a hydraulic cylinder (not illustrated) of a known construction. When this hydraulic cylinder is actuated, the die base 16 is ready to be moveable up and down

guided by the guide rods 17 and consequently the upper punch 32 becomes movable in the vertical direction (pressurizing direction) so that the upper punch 32 can be inserted into the penetrating hole 21 of the vertically movable die 2. According to this configuration, at the time of compression molding, a compression force is applied to the alloy raw meal powder P for molding by the pair of the upper and lower punches 31, 32 within the cavity 22, whereby a molded body of a predetermined shape can be obtained (molding step).

【0019】

In addition, on a periphery of the die 2 there is provided a magnetic field generating apparatus 4 in order to orient in the magnetic field the alloy raw meal powder P inside the cavity 22. The magnetic field generating apparatus 4 is disposed in a symmetrical manner so as to sandwich the die 2 from both sides, and has a pair of yokes 41a, 41b made of a material that is high in magnetic permeability such as mild steel, pure iron, permendur, and the like. Both the yokes 41a, 41b have wound thereabout coils 42a, 42b and, by charging each of the coils 42a, 42b with electric power, there will be generated static magnetic field in a direction X perpendicular to the pressurizing direction (up-and-down direction Y). According to this configuration, the alloy raw meal powder P filled in the cavity 22 can be oriented.

【0020】

The alloy raw meal powder P that is a powder polarized in the magnetic field is manufactured in the following manner. In other words, Fe, B, and Nd are blended in a predetermined composition ratio, and an alloy of 0.05 mm ~ 0.5 mm is first manufactured by a quenching process, e.g., by a strip cast method. On the other hand, an alloy of about 5 mm thick may also be manufactured by a centrifugal casting method, or else a small amount of Cu, Zr, Dy, Al or Ga may be added at the time of blending. Then, the

manufactured alloy is coarsely crushed by a known hydrogen crushing step and is subsequently finely ground by a jet mill fine crushing step in nitrogen gas atmosphere, thereby obtaining alloy raw meal powder of an average particle size of 2 ~10 μm . In this case, if the quenching process is used, the alloy raw meal powder P becomes angular particle shape, each crystal fracture area can be made large, and the clearance among the particles of the alloy raw meal powder P can be made small.

[0021]

In order to improve the flowability, preferably a lubricant is added in a predetermined mixing ratio to the alloy raw meal powder P manufactured as described above. The surface of the alloy raw meal powder P is coated with this lubricant. As the lubricant, solid lubricants or liquid lubricants having a low viscosity are used so that they do not damage the metal mold. As the solid lubricants, there can be listed lamellar compounds (MoS_2 , WS_2 , MoSe , graphite, BN, CF_x , and the like), soft metal (Zn, Pb, and the like), rigid materials (diamond powder, TiN powder, and the like), organic high polymers (PTEE series, aliphatic nylon series, higher aliphatic series, fatty acid amide series, fatty acid ester series, metallic soap series, and the like). It is particularly preferable to use zinc stearate, ethylene amide, and grease of fluoroether series.

[0022]

On the other hand, as the liquid lubricant, there can be listed natural grease material (vegetable oils such as castor oil, coconut oil, palm oil, and the like; mineral oils; petroleum grease; and the like), and organic low molecular materials (low-grade aliphatic series, low-grade fatty acid amide series, low-grade fatty acid ester series). It is particularly preferable to use liquid fatty acid, liquid fatty acid ester, and liquid fluorine lubricant. Liquid lubricants are used with surfactant or by diluting with solvent. The carbon residue content of the lubricants that remains after sintering lowers the

coercive force of the magnet. Therefore, it is preferable to use low molecular weight materials to facilitate the removal in the sintering step.

【0023】

In case a solid lubricant is added to the alloy raw meal powder P, addition may be made in a mixing ratio of 0.02 wt% ~ 0.1 wt%. If the mixing ratio is less than 0.02 wt%, the flowability of the alloy raw meal powder P will not be improved and, consequently, the orientation will not be improved. On the other hand, if the mixing ration exceeds 0.1 wt%, the coercive force lowers under the influence of the carbon residue content that remains in the sintered magnet when the sintered magnet is obtained. Further, in case a liquid lubricant is added to the alloy raw meal powder P, it may be added in a range of 0.05 wt% ~ 5 wt%. If the mixing ratio is less than 0.05 wt%, the flowability of the alloy raw meal powder P will not be improved and, consequently, there is a possibility that the orientation will not be improved. On the other hand, if the mixing ration exceeds 5 wt%, the coercive force lowers under the influence of the carbon residue content that remains in the sintered magnet when the sintered magnet is obtained. By the way, as the lubricants, if both the solid lubricant and the liquid lubricant are added, the lubricants will be widely spread to every corner of the alloy raw meal powder P and, due to high lubricating effect, a higher orientation can be obtained.

【0024】

After filling the cavity 22 formed in the penetrating hole 21 of the die 2 with the alloy raw meal powder P manufactured as described above, the alloy raw meal powder P is compression-molded as a result of pressurizing in the up-and-down direction by the pair of upper and lower punches 31, 32. At that time, it is necessary to enable to improve the magnetic properties by arranging such that a high orientation can be obtained. For that purpose, in this embodiment, there was provided the mixing apparatus 5 that is movable into, and out of, the cavity 22. The molding apparatus 1 is thus constituted

as follows. That is, after having filled the cavity 22 as the filling chamber with the alloy raw meal powder P, prior to the compression molding (molding step) with the pair of upper and lower punches 31, 32, the alloy raw meal powder P in the cavity 22 was arranged to be capable of being oriented (orientation step), while agitating, in the magnetic field in a state in which static magnetic field is generated (in magnetic field) by electrically charging each of the coils 42a, 42b of the magnetic field generating apparatus 4.

【0025】

The agitating apparatus 5 has a supporting plate 51 provided on an upper surface of the die 2 in parallel therewith. The upper surface of the supporting plate 51 is provided with a hydraulic cylinder 52 of a known construction. A pneumatically driven type of motor 53 of a known construction is mounted on a cylinder rod 52a that is projected to the lower side of the supporting plate 51. A rotary vane 54 is mounted (rotary agitation) on the motor 53 at a rotary shaft 53a that is disposed at a position on a longitudinal axial line of the cylinder rod 52a. The rotary shaft 53a and the rotary vane 54 constitute the agitating means. The rotary vane 54 is of a screw vane type (propeller vane). The rotary shaft 53a and the rotary vane 54 are made of a non-magnetic material such as 18-8 stainless steel. By making the rotary shaft 53a and the rotary vane 54 in a non-magnetic material, at the time of agitating the alloy raw meal powder in the magnetic field, the alloy raw meal powder P can be prevented from getting adhered to the agitating means, the adhesion causing insufficient agitation of the alloy raw meal powder P and consequent disturbance in the magnetic field.

【0026】

The supporting plate 51 is mounted on two guide rails 55 elongated in a direction perpendicular to the up-and-down direction X. By sliding the supporting plate 51 along the guide rails 55, the agitating apparatus 5 becomes capable of moving back and forth relative to the cavity 22. In this

case, the powder feeding apparatus may also be mounted on the same guide rails 55 so as to be freely moveable back and forth relative to the cavity 22. Once the agitating apparatus stops at a stopper (not illustrated) provided on the guide rails 55, the rotary shaft 53a is positioned so as to be located on the longitudinal axis of the pair of the upper and lower punches 31, 32. A lid plate 56 made of a non-magnetic material is mounted on the rotary shaft 53a of the motor 53. Once the cylinder 52 is actuated to thereby lower the rotary vane 54 to a predetermined position inside the cavity 22, the lid body 56 comes into abutment with the upper surface of the die 2 to thereby close the upper part of the penetrating hole 21. The lid body 56 thus performs the function of preventing the alloy raw meal powder P from jumping out to the outside of the cavity 22 during agitation.

【0027】

According to this configuration, when the alloy raw meal powder P is oriented in the magnetic field, the flowability of the alloy raw meal powder is improved by adding the lubricant to the alloy raw meal powder P, and the alloy raw meal powder P that is filled into the cavity 22 and is high in flowability is agitated while charging the alloy raw meal powder with the magnetic field. As a result of the above, the positional relationship inside the cavity 22 among the particles of the alloy raw meal powder P can be changed from the state at which it was initially filled into the cavity 22. In combination therewith, as a combined effect, the chances of combining the crystal fractures of the alloy raw meal powder P having more equal crystal orientational relationship increase. Once the crystal fractures having the same crystal orientational relationship get combined, strong bonding chains are formed, and the crystal fractures get joined together without clearance in the direction of magnetic orientation. By executing compression molding in this state, there can be obtained a high-density molded body M (see FIG. 5) without disturbance in the orientation. As a result of increase in the

strength of the molded body, the rate of occurrence of unacceptable products can be lowered and a molded body M (permanent magnet) of high magnetic properties can be obtained. In this case, if a resin binder is mixed with the alloy raw meal powder P to be filled into the cavity 22, rare earth bonded magnet (molded body) of high magnetic properties can be obtained.

[0028]

Then, with reference to FIGS. 1 through 5, a description will be made of the manufacturing of Nd-Fe-B (Nd-Fe-B system) sintered magnet. First, from a waiting position in which each of the upper surfaces of the die 2 and the lower punch 31 are flush with each other and in which the upper punch 32 is positioned at the upper end (see FIG. 1), the hydraulic cylinder is actuated to raise the die 2 to a predetermined position so that a cavity is defined inside the penetrating hole 21. Then, by the powder feeding apparatus (not illustrated), the alloy raw meal powder P that has been weighed in advance and to which a lubricant has been mixed in a predetermined mixing ratio is filled into the cavity 22, and the powder feeding apparatus is retreated. In this case, the charging density of the alloy raw meal powder P in the cavity 22 is set to be 2.2 ~ 3.9 g/cc in order to prevent the alloy raw meal powder P from getting unbalanced or in order to leave freedom to move at the time of agitation (see FIG. 2).

[0029]

Then, the agitating apparatus 5 is moved so that the rotary shaft 53a of the motor 53 is positioned on the longitudinal axis of the pair of upper and lower punches 31, 32 (see FIG. 2). Then, the motor 53 and the lid plate 56 are lowered through the hydraulic cylinder 52. The lid body 56 thus comes into abutment with the upper surface of the die 2, thereby blocking the upper surface of the penetrating hole 21. At the same time, the rotary vane 54 is buried in the alloy raw meal powder P filled into the cavity 22 (see FIG. 3). In this state, the coils 42a, 42b of the magnetic field generating apparatus 4

are charged with electric power and, in the magnetic field, the motor 53 is actuated to rotate the rotary vane 54 in the cavity 22 (orienting step). In this case, in order to obtain a high orientation, it is preferable to agitate with the agitating apparatus 5 in the magnetic field of a range of 5 kOe ~ 30 kOe, preferably, 10 kOe ~ 26 kOe. If the magnetic field intensity is weaker than 5 kOe or stronger than 30 kOe, a sintered magnet of high orientation and high magnetic properties cannot be obtained. In addition, in order for the alloy raw meal powder P filled into the cavity 22 to be mixed in its entirety, the number of rotation of the rotary vane 54 is set to 100 ~ 50000 rpm, preferably to 4000 rpm, and the rotary vane is actuated for a predetermined period of time (1 ~ 5 seconds).

[0030]

According to this configuration, even if the upper punch or the lower punch is subjected to vibrations as in the conventional method, in case the crystal fracture of the raw meal powder particles P1 that lie next to one another in the direction of magnetic field orientation do not meet each other, there will remain clearance among the alloy raw meal powder particles P1. This results in failure to array the alloy raw meal powder particles P1 in the direction of the magnetic field orientation. If the compression molding is performed in this state, the orientation gets disturbed. Like in the embodiment, on the other hand, by orienting while agitating the alloy raw meal powder P in a state in which the magnetic field is charged thereto, the positional relationship among the particles of the alloy raw meal powder P within the cavity 22 will vary from the state in which the alloy raw meal powder was filled into the cavity 22. There will thus be many chances for the crystal fractures of the alloy raw meal powder P that has more equal crystal orientational relationship to be combined. Once the crystal fractures having equal crystal orientational relationship get bonded with one another, there will be formed a strong bonding chain. As shown in FIG. 4(b), the

crystal fractures get joined without clearance in the direction of magnetic orientation in a manner to form a bar-shape, thereby arraying in the direction of orientation of the magnetic field.

【0031】

Then, once the agitation of the alloy raw meal powder P in the magnetic field has been finished, the cylinder rod 52a is lifted to the position in which the rotary vane 54 is away upward of the die 2, and thereafter the agitating apparatus 5 is slid along the guide rails 55 to thereby retract it. In this case, the electric charging to the coils 42a, 42b will not be stopped. Then, the die base 16 is lowered to insert the upper punch 32 from the upper side into the penetrating hole 21. In a state in which the magnetic field is charged, compression molding of the alloy raw meal powder P inside the cavity 22 is started by the pair of the upper and lower punches 31, 32.

【0032】

After a lapse of a predetermined time, the electric charging to the coils 42a, 42b is stopped and, in this state, compression molding at the maximum pressure will be executed. Finally, the upper punch 32 is gradually lifted to thereby gradually reduce the pressure. The compression molding is finished and the molded body M is formed (molding step). According to the above operations, compression molding is performed in a state in which the alloy raw meal powder is joined in a direction of magnetic field orientation just like molding a bar shape without clearance among the crystal fractures so as to be in an array in the magnetic field orientation. Therefore, there can be obtained a high-density molded body M (permanent magnet) without disturbance in the orientation, and the magnetic properties are also improved.

【0033】

The molding pressure in the molding step is set to a range of $0.1 \sim 1$ t/cm², more preferably to $0.2 \sim 0.7$ t/cm². At the molding pressure, e.g.,

below 0.1 t/cm^2 , the molded body does not have a sufficient strength. For example, it gives rise to cracks when the molded body is taken out of the cavity 22 of the molding apparatus. On the other hand, at a molding pressure exceeding 1 t/cm^2 a high pressure is exerted on the alloy raw meal powder P inside the cavity 22 and, as a result, molding is made while orientation is struck out of shape and also there is a possibility that the molded body gives rise to cracks and splits. In addition, the intensity of the magnetic field in the molding step is set to a range of $5 \text{ kOe} \sim 30 \text{ kOe}$. If the intensity of the magnetic field is weaker than 5 kOe , there cannot be obtained a product high in orientation and high in magnetic properties. On the other hand, if the intensity of the magnetic field is stronger than 50 kOe , the magnetic field generating apparatus becomes too large to be practical.

【0034】

Subsequently, after having demagnetization by charging reverse magnetic field of, e.g., 3 kOe , the die 2 is lowered to the lower end. The molded body M inside the cavity 22 will then be pulled out to the upper surface of the die 16. The die base 16 is moved to thereby move the upper punch 32 to the upper end, and then the molded body is taken out. Finally, the obtained molded body is contained in a sintering furnace (not illustrated) to execute sintering for a predetermined period of time at a predetermined temperature (1000°C) in, e.g., Ar atmosphere (sintering step). Further, aging treatment is executed in Ar atmosphere for a predetermined period of time at a predetermined temperature (500°C), thereby obtaining a sintered magnet (Nd-Fe-B sintered magnet).

【0035】

In this embodiment, a description has been made of a uniaxial pressurizing system in which the molding direction is perpendicular to the direction of magnetic field. Without being limited thereto, there may be used a molding apparatus in which the molding direction is in parallel with

the direction of the magnetic field. In addition, in this embodiment, as the orientation magnetic field at the time of agitation and molding, there was used a static magnetic field in which the intensity per unit time of the magnetic field does not change. Without being limited thereto, there may be used, as shown in FIG. 6, a magnetic pulse field in which the intensity of magnetic field per unit time varies at a predetermined cycle. In this case, as shown in FIG. 7, it may be so arranged that reverse magnetic field is charged.

【0036】

According to this configuration, since vibrations can be applied to the alloy raw meal powder P at the time of agitation and molding of the alloy raw meals powder P, the orientation can further be improved. In this case, the period of pulse is preferably 1 ms ~ 2 s and it is preferable to set the non-output time below 500 ms. If this range is exceeded, strong bonding chains will be broken, with the result that a high orientation cannot be obtained. In addition, in case the magnetic pulse field is charged, the peak value shall preferably be set to 5 ~ 50 kOe. If the magnetic field intensity is weaker than 5 kOe, there cannot be obtained a product high in orientation and high in magnetic properties. On the other hand, if the magnetic field is stronger than 50 kOe, the magnetic field generating apparatus becomes too large to be practical.

【0037】

In the embodiment, a description has been made of an example in which a rotary vane 54 of screw vane type is used as the agitating means (rotary agitation). However, without being limited thereto, there may be used one in which a rectangular scoop (not illustrated) provided with a driving means such as a pneumatic cylinder is attached to a front end of the cylinder rod 52a of the hydraulic cylinder 52 so as, in a state in which the scoop is buried into the alloy raw meal powder P, to reciprocate the scoop horizontally over the entire length in the radial direction of the cavity 22 at a predetermined cycle

(horizontal agitation). In this case, at the time of rotary agitation or horizontal agitation, the cylinder rod 52a may be moved up and down so as to mix the whole of the alloy raw meal powder P in the cavity 22.

【0038】

Regarding the rotary vane 54 in the case of rotary agitation, as long as mixing can be made, during agitation, so as to mix the whole of the alloy raw meal powder P in the cavity 22, there is no particular limitation. It may be of the type to generate air flow, but preferably it shall be of a shape that hardly crushes the alloy raw meal powder during agitation. As shown in FIG. 7, as the rotary vane, there may be employed: a paddle vane type in which substantially L-shaped plate pieces 54a are provided on the rotary shaft while deviating by 90 degrees (see FIG. 7(a)); a ribbon vane type in which vanes 54b are provided spirally (see FIG. 7(b)); and an anchor vane type in which plate pieces 54c are provided so as to extend horizontally relative to the rotary shaft (see FIG. 7(c)). Depending on the selected rotary vanes, the number of rotation and time of agitation are appropriately set. On the other hand, not only the rotary agitation and horizontal agitation as the agitation means, there may be employed one in which a gas nozzle is provided at the front end of the cylinder rod 52a to thereby constitute an agitating means made of a non-magnetic material. A high-pressure gas may thus be intermittently or continuously ejected so as to agitate the alloy raw meal powder P in the cavity 22.

【0039】

In the embodiment, a description has been made of an example in which a uniaxial pressurizing type of compression molding apparatus 1 is used to mold the powder. Without being limited thereto, an isostatic molding apparatus (not illustrated) using a rubber mold may be constituted. In this case, this rubber mold constituting the filling chamber is filled with alloy raw meal powder P, and then an orienting step is performed to agitate in the

magnetic field by the agitating apparatus 5. On the other hand, there may be performed a second molding step in which the molded body M obtained by the molding step in the uniaxial pressurizing type of compression molding apparatus 1 is further molded by using the isostatic molding apparatus. According to this configuration, the occurrence of cracks and splits in the molded product can be reduced.

【0040】

Further, in the embodiment, the compression molding apparatus 1 was used to manufacture an oriented body by orienting in the magnetic field while agitating the alloy raw meal powder P in the magnetic field. Subsequently, compression molding was executed in a state of charging the magnetic field. However, the following way may be employed. That is, the alloy raw meal powder that has been obtained in the above procedure is filled into a box body of Mo make having an upper opening and is subjected to agitation by the above-described agitating apparatus 5 for a predetermined period of time in a static magnetic field. Thereafter, the agitating apparatus 5 is retracted and, without demagnetizing, a lid of Mo make is mounted on the upper opening of the lid body. Thereafter, the magnetic field is attenuated and subsequently the box body with the lid mounted is placed as it is into a sintering furnace for sintering to obtain a permanent magnet (sintered body). In this case, the intensity of the magnetic field is set to 12 kOe, and the box body is formed into a cube of 7 cm. And a sintered body was obtained by setting the number of rotation of the agitating apparatus 5 to 40000 rpm and the time of agitation to 2 seconds. As a result, average magnetic properties of $B_r = 15.01$ kG, $(BH)_{\max} = 55.1$ MG Oe and the degree of orientation of 99% were obtained.

【0041】

Further, in the embodiment, a description has been made of an example of manufacturing a sintered magnet. However, this molding apparatus 1

can be applied to manufacturing of an oriented body by orienting powder which polarizes in the magnetic field or electric field, and then by subjecting this oriented body to compression molding. For example, there can be listed the manufacturing of silicon nitride (Si_3N_4) by molding a predetermined powder in the magnetic field and then sintering it.

【Brief Description of the Drawings】

【0042】

FIG. 1 is a schematic view of a molding apparatus for executing the method of manufacturing according to this invention in a standby position;

FIG. 2 is a schematic view illustrating the operation of the molding apparatus as shown in FIG. 1;

FIG. 3 is a schematic view illustrating the operation (orienting step) of the molding apparatus as shown in FIG. 1;

FIG. 4(a) is a schematic view illustrating the magnetic field orientation according to the conventional art, and FIG. 4(b) is a schematic view illustrating the agitating magnetic field orientation of this invention;

FIG. 5 is a schematic view illustrating the operation (molding step) of the molding apparatus as shown in FIG. 1;

FIG. 6 is a graph illustrating the magnetic pulse field;

FIG. 7 is a graph illustrating a modified example of the magnetic pulse field; and

FIG. 8(a) through FIG. 8(c) are perspective views showing other embodiments of rotary vanes to be used in an agitating apparatus.

【Description of Reference Numerals】

【0043】

- 1 compression molding apparatus
- 2 die
- 21 penetrating hole
- 22 cavity

31, 32 punches

4 magnetic field generating apparatus

5 agitating apparatus

54 rotary vane

56 lid body

P alloy raw meal powder

WHAT IS CLAIMED IS:

1. A molding apparatus comprising:
a filling chamber filled with powder that is polarized in one of magnetic field and electric field;
means for generating one of magnetic field and electric field so as to enable to charge the powder filled in the filling chamber with one of the magnetic field and electric field;
an agitating means for agitating and orienting the powder in a state of being charged with one of the magnetic field and electric field; and
a pressurizing means for applying a compression force in one of the magnetic field and electric field to the powder that has been agitated and oriented, thereby molding the powder.
2. The molding apparatus according to claim 1, wherein the agitating means is disposed in a manner to be movable into and out of the filling chamber.
3. The molding apparatus according to claim 1 or 2, wherein the filling chamber has an opening for filling the powder therethrough, and wherein a lid body is provided integral with the agitating means in a manner to close the opening when the agitating means is moved into the filling chamber.
4. The molding apparatus according to any one of claims 1 through 3, wherein the agitating means is constituted by a non-magnetic material.
5. The molding apparatus according to any one of claims 1 through 4, wherein the means for generating the magnetic field is capable of generating static magnetic field in a range of magnetic field intensity of 5~30 kOe.

6. The molding apparatus according to any one of claims 1 through 4, wherein the means for generating the magnetic field is capable of generating magnetic pulse field in a range of magnetic field intensity of 5~50 kOe.

7. The molding apparatus according to any one of claims 1 through 6, wherein the powder is alloy raw meal powder for rare-earth magnet, the alloy raw meal powder being manufactured by quenching method.