The present invention relates to a metal powder sintered body by using fine powders as the raw material and the fabrication method thereof. The sintered body has a characteristic composition including iron (Fe), carbon (C), nickel (Ni) and at least one strengthening element, in the ratios as follows: Ni: 3.0-12.0%, carbon: 0.1-0.8%, the strengthening element: 0.5-7.0%, and the remaining portion being Fe. The sintered body has high tensile strength, high hardness, and good ductility, without treatment with the quenching process.
METHOD FOR MAKING SINTERED BODY WITH METAL POWDER AND SINTERED BODY PREPARED THEREFROM

CROSS-REFERENCE TO RELATED APPLICATION


BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention generally relates to a sintered body and fabrication method thereof. More particularly, the present invention relates to compositions of sinter-hardening powders, the sintered body by using fine powders as raw materials, and the fabrication method thereof.

[0004] 2. Description of Related Art

[0005] As is well known in the art, the design of the alloy of powder metallurgy is always the critical starting point for the development of powder metallurgy. By combining different alloying elements and different amounts of additives, various alloy steels can be developed and applicable to diversified circumstances. In general, powder metallurgy components are required to possess mechanical properties suitable for their application fields. Thus, hardening thermal processes like quenching followed by tempering are normally applied to the sintered components in order to obtain the desirable mechanical properties.

[0006] However, while the quenching is performed, several problems like deformation, size inconsistency, or cracking after quenching may be caused by the fast cooling procedure. In addition, the thermal processes performed on the components will cause additional costs. Therefore, sinter-hardening powders have been developed, by adding high hardenability alloying elements such as molybdenum (Mo), nickel (Ni), manganese (Mn) or chromium (Cr) to iron powders, then pressing out the green compact through the conventional compacting process and then sintering the green compact, with the hardness above HRC30. Examples of alloys produced by this method are Ancorsteel 727SH (Fe-0.42MN-1.40Ni-1.25Mo—C) from Hoegananes Corp. and ATOMET 4701 (Fe-0.45Mn-0.90Ni-1.00Mo-0.45Cr—C) from Quebec Metal Powders Limited. The components made from these powders are cooled at rates of a minimum of 30°C per minute in the sintering furnace to generate martensitic and bainite.

[0007] Although the alloying elements in these sinter-hardening components are still not homogenized completely using the regular sintering conditions of 1120°C and 30-40 minutes, these sinter-hardening powders provide better mechanical properties than those possible using non-sinter-hardening powders. Although sinter-hardening powders can reduce costs due to the elimination of the quenching process, a high cooling rate system has to be installed in the sintering furnace. Furthermore, the aforementioned cooling rates, while slower than quenching, are still fast enough to cause problems such as deformation, inconsistency of the dimensions, and even cracking. According to U.S. Pat. No. 5,682,588, the claimed powders are compacted by the conventional pressing process, sintered between 1130-1230°C, and then cooled at rates of 5-20°C/minute in order to reach the desired sinter-hardening effects. This has improved the process by lowering the minimum cooling rate of 30°C/min, as described in the previously mentioned processes. However, the mechanical properties, in particular, the ductility, are still unsatisfactory.

[0008] Concerning the press-and-sinter process, there are standards (the Year 2003 version) for sinter-hardening alloys set forth by the Metal Powder Industries Federation (MPIF). FLNC-4408 (1.0-3.0% Ni, 0.65-0.95% Mo, 1.0-3.0% Cu, 0.6-0.9% C, and the remaining portion is Fe) is the example with the best mechanical properties. After sinter-hardening and tempering, the above-mentioned alloy can reach a tensile strength of 970 MPa under the density of 7.2 g/cm³, and the hardness can reach HRC30, while the ductility is only 1.0%. Although this press-and-sintered alloy belongs to one of the sinter-hardening type alloys, its mechanical properties are still not satisfactory.

[0009] In the field of powder metallurgy, fine powders are commonly used in the metal injection molding process. In contrast, the powders used in the traditional powder metallurgy process (e.g. press-and-sinter process) are much coarser. The particle size of the powders used in metal injection molding is usually less than 30 μm, while the particles used in the press-and-sinter process are under 150 μm in size. Since the diffusion distances in fine powders are shorter, the added alloying elements can be homogenized more easily in the matrix materials. Therefore, components sintered from the fine powders possess mechanical properties better than those of the traditional press-and-sintered components.

[0010] At present, the alloys commonly used for metal powder injection molding are the Fe—Ni—Mo—C alloy series, exemplified by MIM-4605 (1.5-2.5Ni, 0.2-0.5% Mo, 0.4-0.6% C, <1.0% Si, the remaining portion is Fe), which has the best mechanical properties according to the MPIF standards. This alloy, after sintering, reaches a tensile strength of 415 MPa, a hardness of HRA62, and a ductility of 15%. In order to attain the best mechanical properties, the sintered product has to be heat-treated (quenched and tempered). It then reaches a tensile strength of 1655 MPa, a hardness of HRC48, and a ductility of 2.0%.

[0011] Although excellent mechanical properties of the metal injection molded products can be obtained by heat treatment after sintering, the costs of the heat treatment accounts for a large part of the whole production cost. Hence, it is critical to lower the costs of the heat treatment, for example, by using sinter-hardening materials. However, according to the Metal Powder Industries Federation Standards, no sinter-hardening alloys are listed for the metal injection molding process.

[0012] As mentioned above, application of fine powders improves homogenization of the alloying elements and mechanical properties of the products. However, application of fine powders in the traditional press-and-sinter process is difficult because of the poor flowability of the powder, which in turn makes it difficult to fill the powders into the die cavity, and thus automated pressing can not be used. However, this problem can be overcome by granulating the fine powders into large spherical particles, and the granulated powders can then be applied in the press-and-sinter process.
REFERENCE PAPERS


SUMMARY OF THE INVENTION

[0028] The present invention is directed to a metal powder sintered body, by using a new composition and by using fine powders as the raw material. The particle size of the powders is between 0.1-30 μm. The sintered body fabricated has high hardenability and the sintered body can attain excellent mechanical properties under the normal cooling rate (3-30°C/minute) inside the traditional sintering furnace.

[0029] In accordance with one aspect of the present invention, a metal injection molding fabrication method is provided, by using the new compositions of the sinter-hardening metal powders in the conventional metal injection molding process. The sintered compact can be treated with low temperature tempering, without quenching, to obtain excellent mechanical properties.

[0030] In accordance with another aspect of the present invention, a powder metallurgy fabrication method is provided by using the new compositions of the sinter-hardening metal powders in conventional powder metallurgy processes (press-and-sinter process). The sintered compact can be treated with low temperature tempering, without quenching, to obtain excellent mechanical properties.

[0031] According to the above-mentioned and the other purposes of the present invention, a metal powder sintered body is provided, by using fine powders as the raw material with the sintered body containing the characteristic composition including iron (Fe), carbon (C), nickel (Ni), and at least one other strengthening element, in the ratios as follows: Ni: 3.0-12.0%, carbon: 0.1-0.8%, the strengthening elements: 0.5-7.0%, and the remaining portion is Fe. The above-mentioned strengthening elements can be selected from the group consisting of Molybdenum (Mo), Chromium (Cr), Copper (Cu), Titanium (Ti), Aluminum (Al), Manganese (Mn), Silicon (Si), and Phosphorous (P). The element carbon mentioned above can be provided by adding graphite or using carbon-containing carbonyl iron powders. The sintered body of the above-mentioned powders has a tensile strength of over 1450 MPa, a hardness of over HRC38, and a ductility of over 1% without the use of any quenching process.

[0032] According to the above-mentioned and the other purposes of the present invention, a metal injection molding fabrication method is provided. The above-mentioned compositions of the sinter-hardening metal powders can be applied to metal injection molding. The method comprises providing the powders and binders, while the diameters of
elemental or alloyed powders are 0.1–30 μm. The above-mentioned powders and binders are homogenously kneaded to form a feedstock. The green compacts are then molded from the feedstock using the injection molding machine. The binders in the above-mentioned green compacts are removed using the well-known solvent or thermal debinding methods. The debound body is sintered and cooled at a cooling rate of 3-30° C./minute in the sintering furnace, which can be a regular furnace, such as a vacuum furnace or a continuous pusher furnace. The process after sintering is the low temperature tempering process with the tempering temperature ranging from 150-400° C. and the time ranging from 0.5-5 hours, to improve the mechanical properties of the sintered body.

[0037] FIG. 1 is a cross-sectional view of the sample in example 1, observing the ductile microstructure with dimple type fractures by the scanning electronic microscope.

DESCRIPTION OF THE EMBODIMENTS

[0038] The foregoing descriptions of specific embodiments of the invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to explain the principles and the application of the invention, thereby enabling others skilled in the art to utilize the invention in its various embodiments and modifications according to the particular purpose intended. The scope of the invention is intended to be defined by the claims appended hereto and their equivalents.

[0039] The element ingredients and the mechanical properties of the sintered body are listed in Table 1 and Table 2, whereas examples 1-4 in Table 2 are the sintered bodies made from the metal injection molding process; examples 5-6 are the sintered body made from the traditional powder metallurgy process. Table 1 and Table 2 are used to illustrate the sintered body elements and the fabrication method for the present invention, while examples 1-6 represent the present invention and examples A-D are used as the comparison group according to the available literatures.

EXAMPLE A

[0040] According to the standards from the MPIF-35, the elements of MIM-4605 used in injection molding are shown in Table 1, while the mechanical properties of the sintered body produced by the elements of MIM-4605 are shown in Table 2.

EXAMPLE B

[0041] Same composition as in example A. After the heat treatment, products improve enormously in terms of mechanical properties, as shown in Table 2.

EXAMPLE C

[0042] According to the MPIF-35 standards, the elements of MIM-2700 used in injection molding are shown in Table 1, while the mechanical properties of the sintered body produced by the elements of MIM-2700 are shown in Table 2.

EXAMPLE D

[0043] According to the MPIF-35 standards, the elements of sinter-harden alloy FLNC-4408 used in the traditional press-and-sinter process are shown in Table 1, while the mechanical properties of the sintered body produced by the elements of FLNC-4408 are shown in Table 2.

EXAMPLE 1

[0044] Following Table 1, the required powders with particle sizes ranging from 0.1–30 μm are mixed together with 7 wt % of the binder, mixed in the Z type high shear rate mixer at 150° C. for 1 hour, then cooled to room temperature to obtain the granulated feedstock. Thereafter, the previously
The mentioned granulated feedstock is filled into the injection molding machine to produce the tensile test bar (e.g. the standard tensile bar from the MPIF-50 standard). The tensile bar is de-bound under the procedure applied from the known arts in the industry, for example, debinding for five hours using heptane as the solvent at 50°C, then heating the tensile bar in the vacuum furnace from the room temperature up to 650°C at a rate of 5°C/minute, raising the temperature to 1200°C at a rate of 10°C/minute, sintering at 1200°C for two hours, and then cooling to room temperature, so as to reach a hardness of HRC51 and a ductility of 1.0%. The tensile bar, after being tempered at 180°C for two hours, reaches a tensile strength of 1800 MPa, a hardness of HRC45, and a ductility of 3%, as shown in Table 2. **FIG. 1** is a fracture surface of the sample in example 1. The ductile microstructure with dimple type fractures is observed using a scanning electronic microscope. This indicates that products of high hardness, high tensile strength, and high ductility can be produced from these alloying elements. Take the as-sintered MIM-4605 as an example, which is an injection molding material with the best mechanical properties listed by the MPIF. The properties are 415 MPa, HRB62, and 15% ductility, as shown in example A in Table 2. After quenching and tempering, the improved MIM-4605 will possess 1655 MPa, HRC48, and a ductility of 2%, as shown in example B in Table 2. MIM-4605 needs to be quenched and tempered to reach the mechanical properties similar to those made by the present invention. However, the sintered body of the present invention possesses good mechanical properties without the need for quenching.

**EXAMPLE 2**

The same processes as in example 1 but with the compositions listed in example 2 in Table 1. After tempering, the tensile bar has a tensile strength of 1780 MPa, a hardness of HRC-45, and a ductility of 4%.

**EXAMPLE 3**

The same processes as in example 1, but with the compositions listed in example 3 in Table 1. After tempering, the tensile bar has a tensile strength of 1720 MPa, a hardness of HRC-46, and a ductility of 4%.

**EXAMPLE 4**

The same processes as in example 1, but with the compositions listed in example 4 in Table 1. After tempering, the tensile bar has a tensile strength of 1450 MPa, a hardness of HRC-28, and a ductility of 4%.

**EXAMPLE 5**

Following the compositions listed in example 5 in Table 1, the powders having particle sizes ranging from 0.1–30 µm and the required components are mixed together with 1.5 wt % of the binders. The powders, water, and binders (e.g.: Polyvinyl alcohol) are blended into a slurry. The slurry is then atomized from the nozzle at high speed and dried by hot air or hot nitrogen to evaporate the water within. The fine powders are thus bonded with each other by the binder to form granulated powders with good flowability. The particle size of the graduated powder is about 40 µm. The previously mentioned granulated powders are filled into the die cavity to produce the green tensile bar by the automatic compacting machine. The tensile bar is de-bound under the procedure applied from the known arts in the industry. For example, the temperature will be raised at the rate of 5°C/minute up to 400°C, and then at the rate of 3°C/minute up to 1100°C, maintained for one hour, and then raised at the rate of 10°C/minute up to 1200°C, and sintering will continue at this temperature for one hour. Afterwards, the tensile bar is cooled as the temperature of the furnace drops, and the tensile bar is tempered for 2 hours at 180°C without the use of the quenching process. As shown in Table 2, the tensile bar has a tensile strength of 1690 MPa, a hardness of HRC47, and a ductility of 3%. Compared to FLNC-4408 (the best sinter-hardened press-and-sinter work piece listed by the MPIF), FLNC-4408 has 970 MPa, HRC30, and 1% ductility, as shown in example D in Table 2.

**EXAMPLE 6**

The process is the same as in example 5, but with the compositions as shown in example 6 in Table 1. After 2 hours of tempering at 180°C, the tensile bar possesses a tensile strength of 1650 MPa, a hardness of HRC43, and a ductility of 4%.

**TABLE 1**

Commonly used percentages and elements for the examples 1–6 in the present invention and for cases A–D from the industry and based on the Metal Powder Industries Federation (MPIF) standards (weight percentage, wt %)

<table>
<thead>
<tr>
<th>Element</th>
<th>Ex: 1</th>
<th>Ex: 2</th>
<th>Ex: 3</th>
<th>Ex: 4</th>
<th>Ex: 5</th>
<th>Ex: 6</th>
<th>Ex: A &amp; B</th>
<th>Ex: C</th>
<th>Ex: D</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.36%</td>
<td>0.34%</td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.4%</td>
<td>0.5%</td>
<td>0.4%–0.6%</td>
<td>&lt;0.1%</td>
<td>0.6–0.9%</td>
</tr>
<tr>
<td>Ni</td>
<td>8.0%</td>
<td>9.0%</td>
<td>8.0%</td>
<td>4.5%</td>
<td>8.0%</td>
<td>7.5%</td>
<td>1.5–2.5%</td>
<td>6.5–8.5%</td>
<td>1.0–3.0%</td>
</tr>
<tr>
<td>Mo</td>
<td>0.8%</td>
<td>0.8%</td>
<td>1.0%</td>
<td>1.0%</td>
<td>0.8%</td>
<td>0.8%</td>
<td>0.2–0.5%</td>
<td>&lt;0.5%</td>
<td>0.65–0.95%</td>
</tr>
<tr>
<td>Cr</td>
<td>0.8%</td>
<td>0.8%</td>
<td>0.8%</td>
<td>0.5%</td>
<td>0.8%</td>
<td>0.5%</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Mn</td>
<td>0.6%</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>Cu</td>
<td>—</td>
<td>—</td>
<td>1.5%</td>
<td>—</td>
<td>0.5%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Si</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.3%</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>—</td>
</tr>
<tr>
<td>Fe</td>
<td>the rest</td>
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<td>the rest</td>
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<td>the rest</td>
<td>the rest</td>
<td>the rest</td>
<td>the rest</td>
<td>the rest</td>
</tr>
<tr>
<td>Ex.</td>
<td>Density (g/cm³)</td>
<td>Quench-hardening process</td>
<td>Tensile strength (MPa)</td>
<td>Hardness</td>
<td>Ductility (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
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<td>415</td>
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<td>B</td>
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<td>1655</td>
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<td>D</td>
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<td>970</td>
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<td>None</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>7.6</td>
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<td>HRC45</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>7.5</td>
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<td>7.5</td>
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<td>1630</td>
<td>HRC43</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Austenitized at 860°C and then oil quenched, then tempered at 180°C for 2 hours.
**Sintered and then tempered at 180°C for 2 hours.

In conclusion of the above description, compared to the best injection molding alloy, MIM-4605 (after quenching and tempering), and the best sinter-hardening alloy, FLNC-4408, for the press-and-sinter work piece, listed by the Metal Powder Industries Federation (MPIF); the sinter-hardening alloy of the present invention can attain similar or even better mechanical properties without the quench-hardening process. Besides, the problems derived from quench-hardening in the prior art, including deformation, inconsistency of the dimensions, and cracking after quenching, etc., can be avoided in the present invention, and the costs from the quench-hardening process can be eliminated. Although sinter-hardening alloys are available for the pressing process in traditional powder metallurgy, the cooling rate required for the sintered body is much higher than that required in this study. The sintered body of the present invention provides excellent mechanical properties, and it also provides advantages in the areas of dimensional control and lower costs.

It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A metal powder sintered body by using fine powders as a raw material, and an alloy of the sintered body comprising:
   - Iron (Fe), Carbon (C), Nickel (Ni) and at least one strengthening element, wherein the alloy includes 3.0-12.0% nickel, 0.1-0.8% carbon, and 0.5-7% the strengthening element, while a remaining portion of the alloy is iron, and diameters of the fine powders range from 0.1-30 μm.

2. The sintered body as recited in claim 1, the strengthening element is selected from the group consisting of Molybdenum (Mo), Chromium (Cr), Copper (Cu), Titanium (Ti), Aluminum (Al), Manganese (Mn), Silicon (Si), and Phosphorous (P).

3. The sintered body as recited in claim 1, wherein a source of carbon is from graphite.

4. The sintered body as recited in claim 1, wherein a source of carbon is from carbonyl iron powder.

5. The sintered body as recited in claim 1, wherein the sintered body has a tensile strength over 1400 MPa, a hardness over HRC35, and a ductility over 1%.

6. A method for fabricating the sintered body as recited in claim 1, comprising:
   - providing powders and binders;
   - kneading the powders and the binders, so that the powders and the binders mix into a homogenous feedstock;
   - performing an injection molding process so as to discharge the feedstock to obtain a green compact;
   - debinding the green compact to remove the binders in order to form a body;
   - sintering and cooling the body in a sintering furnace; and performing a post-sintering thermal process.

7. The method as recited in claim 6, wherein the powders are elemental powders or prealloyed powders with diameters ranging from 0.1-30 μm.

8. The method as recited in claim 6, wherein the sintering furnace is a vacuum furnace or a continuous furnace.

9. The method as recited in claim 6, wherein sintering conditions for the sintered body include a sintering temperature of 1100-1350°C for 0.5-5 hours, and a cooling rate of 3-30°C/minute.

10. The method as recited in claim 6, wherein the post-sintering thermal process is a low temperature tempering process, with a tempering temperature ranging from 150-400°C for 0.5-5 hours.

11. The method as recited in claim 6, wherein the sintered body has a tensile strength over 1400 MPa, a hardness over HRC35, and a ductility over 1%.

12. A method for fabricating the sintered body as recited in claim 1, comprising:
   - providing powders and binders;
   - performing a powder granulation process so that the powders and the binders are joined into round granules;
   - sieving the round granules to select granules with a predetermined flowability for a compacting machine;
   - performing a compacting process by filling the granules into a die cavity and pressing them out, so as to generate a green compact;
   - debinding the green compact to remove the binders to form a body;
   - sintering and cooling the body inside a sintering furnace; and
   - performing a post-sintering thermal procedure.

13. The method as recited in claim 12, wherein the powders are elemental powders or prealloyed powders with dimensions ranging from 0.1-30 μm.

14. The method as recited in claim 12, wherein the sintering furnace is a vacuum or a continuous furnace.

15. The method as recited in claim 12, wherein sintering conditions for the sintered body include a sintering temperature of 1100-1350°C for 0.5-5 hours, and a cooling rate of 3-30°C/minute.
16. The method as recited in claim 12, wherein the post-sintering thermal process is a low temperature tempering process, with a tempering temperature ranging from 150-400°C for 0.5-5 hours.

17. The method as recited in claim 12, wherein the sintered body has a tensile strength over 1400 MPa, a hardness over HRC35, and a ductility over 1%.

* * * * *