

Double-layer Metal Sheet and Method of Fabricating the Same

Background and Field of the Invention

5 This invention relates to a method for bonding two metal powder components having different shrinkage factors using powder metallurgy, more particularly but not exclusively, for fabricating double layer metal parts, sheets or components.

10 It is widely known that formation or fabrication of a double layer metal component using powder processing requires an intermediate gradient material composition disposed between the two layers of metal powder. The intermediate gradient material is a mixture of the two material powders to be bonded to mutually compensate the respective shrinkage factor of each
15 material and thus provides a region or zone to allow a gradual change between the two material powders when the two layers are sintered together. This alleviates deformation or warpage of the two layers during sintering.

However, the use of the intermediate gradient zone creates extra process steps
20 of preparing the intermediate mixture and arranging the mixture between the two layers during the fabricating process which may further complicate the process.



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It is an object of the present invention to provide a bonding method which alleviates at least one of the disadvantages of the prior art and/or provides the public with a useful choice.

5 Summary of the Invention

In a first aspect of the invention, there is provided a method of bonding two metal powder components having different shrinkage factors, the method comprising the steps of:

- 10 i. mixing one of the powder components with a powder binder to reduce the shrinkage difference between the powder components, thereby forming a powder component mixture,
- ii. forming a green compact from the powder component mixture and the other metal powder component,
- 15 iii. sintering the compact to form a permanent bond between the two powder components, and
- iv. applying pressure on a surface of the compact during the sintering step (iii).

Other specific aspects of the invention may be found in claims 22 and 23.

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An advantage of the described embodiment of the invention is that the two metal powder components can be bonded without an intermediate gradient zone. The use of an appropriate amount of pressure during the sintering process helps to control the shrinkage of the compact and reduces or prevents
25 warping thereof.

Preferably, the powder binder reduces the shrinkage difference between the two metal powder components such that the shrinkage factor of one metal powder component is substantially matched to that of the other metal powder component.

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The other metal powder component may also be mixed with powder binder before the compacting step (ii). The powder binder for one powder component may be the same or different from that used for the other metal powder.

10 Preferably, one of the metal powder is mixed with three to five weight % of powder binder.

Preferably, the method further comprises a step of removing the powder binder in a debinding furnace prior to the sintering step. Alternatively, the powder
15 binder is removed in a sintering furnace followed by the sintering step.

In one embodiment, the green compact is formed in a suitably shaped die and the method further comprises the steps of arranging one of the powder component mixtures in the die as a base layer, arranging the other powder
20 component mixture on top of the base layer; and compressing the powder component mixtures together to form a desired shape of the compact.

Preferably, the pressure applied on the surface of the compact during the sintering step is between 2 g/cm^2 and 10 g/cm^2 . Alternatively, the pressure
25 applied on the surface of the compact during the sintering step may be more

than 10 g/cm². Preferably, the required pressure is produced by a ceramic plate. As an example, the ceramic plate may be placed directly on the surface of the compact during the sintering step to exert the required amount of pressure. As a further example, the ceramic plate may be spaced from the compact such that the space between the plate and the compact may be 50 to 100 microns.

In another embodiment, the green compact may be formed by tape casting and the method further comprises the step of mixing the powder component mixtures with a solvent and polymer binder to form respective slurry mixtures prior to the compacting step. Preferably, the method further comprises the steps of layering one slurry mixture on top of the other to form a double layer slurry and heating the double layer slurry to form the compact.

The compact may also be formed by powder rolling.

The present invention also relates to a metal part, double layer or multi-layer plate or part produced using the method for different materials.

Brief Description of the Drawings

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings in which,

Figure 1 is a flow chart depicting a preferred method for producing a double layer component without an intermediate gradient zone using powder metallurgy;

Figure 2 shows a die set used in the method of Figure 1;

5 Figure 3 shows a sintered double layer component according to the preferred embodiment;

Figure 4 shows a microstructure view of the double layer component of Figure 3;

Figure 5 shows a microstructure view of another double layer component
10 produced using the method of Figure 1;

Figures 5a and 5b show microstructure views of two further double layer components produced using the method of Figure 1;

Figure 6 shows a method of applying pressure on a surface of a green compact during sintering; and

15 Figure 7 shows a tape casting apparatus for forming a double layer green compact.

Detailed Description of the Preferred Embodiment

20 A preferred embodiment of the invention will be described using an example of fabricating a double layer metal plate using powder metallurgy and Figure 1 shows a flowchart depicting the fabrication steps.

In this embodiment, an iron (Fe) based powder material, hereinafter referred to
25 as powder A is used to form the first metal layer. For the second metal layer,

nickel (Ni) powder is used. It should be apparent that the described embodiment is also applicable to other types of metal such as titanium (Ti), stainless steel metal powder or other alloys.

5 Powders A and B have different shrinkage factors and to reduce the shrinkage difference, a powder binder, such as wax powder binder is used. As shown in Figure 1, at step 1.1, powders A and B are separately mixed with respective proportions of the powder binder using an experimental blender.

10 In this embodiment, to achieve the desired results, typically powder B is mixed or blended with 3 to 5 wt % wax powder binder whereas powder A is mixed with 5 to 15 wt % powder binder. To further reduce the effects of warping or distortion during sintering, it is preferred that layer and binder formulation is optimised at about 5 wt % binder for the base layer (powder B) and about 7 wt
15 % binder for the top layer (powder A). It should be apparent that the above binder and material wt. proportions are only examples and the proportions may be varied according to the types of powder materials used since different material have different shrinkage characteristics and the proportions may be determined by trial and error to obtain satisfactory results.

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When both powders A and B are properly mixed, the powder mixtures are further processed or consolidated in a suitably shaped die to obtain a self-supporting compact or green body, and in this embodiment a die set 20 shown in Figure 2 is used to form the required shape of the double layer plate. The die
25 set 20 comprises a base die 21 having a cavity 21a, an upper die 22a and an

ejector/lower die 22b. The ejector 22b is first arranged in the cavity 21a of the base die 21 prior to the step of consolidating the powder mixtures in the die set 20.

- 5 At step 1.2, the powder mixture including powder A, which is the base layer, is spread evenly on the ejector 22b to form the desired thickness, which in this particular case is approximately 700 to 950 microns. At step 1.3, the process is repeated for the powder mixture containing powder B as the coating or top layer with a lesser layer thickness of about 50 μ m.

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- Next, at step 1.4, both layers are compressed to shape or compacted together using the upper die 22 to form a compact commonly known as a green body 23 of a desired shape such as that shown in Figure 2. In this particular case, the green body 23 has dimensions as depicted in Figure 2. The compression force
15 applied on the upper die 22 is about 25 tons. The green body 23 is unsintered but possess sufficient green strength to be ejected (using the ejector 22b) as an integrated part from the base die 21 ready for the next process step. Typically, the green body 23 is formed at room temperature. Alternatively and preferably, the green body 23 may be formed at a temperature between 40°C and 90°C.

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It would be appreciated that the compacting can be performed before the powder mixture containing powder B is layered onto powder A. This means that after the powder mixture containing powder A is arranged on the base die 21, the upper die 22 is used to compress powder A first and when the mixed

powder of powder B is subsequently arranged on top of powder A, the upper die 22 is used again to compact the composition.

Next at step 1.5 and prior to the sintering step 1.6, preferably the green body is thermally debinded to remove the binder materials at a temperature of up to 900°C with a heating rate between 1°C to 3°C per minute. The holding time at the maximum temperature is about 0.5 to 2.5 hours. The purpose of the debinding is to remove the binders completely prior to sintering, so that when the parts are sintered in a separate furnace, there will be no contamination to the furnace and the parts from the residual binders.

At step 1.6 , the green body 23 is subject to a sintering process and it is at this step the two layers are permanently bonded together to form a double layer plate . Sintering requires heating the green body 23 in a furnace, typically a batch or continuous furnace, at below the melting point of the lower melting temperature of either powder A or B. Atomic diffusion takes place and the boundary between powders A and B "grow" to create a permanent and strong bond. For this case, the green body is subjected to a sintering temperature of 1200°C with a heating rate of 2°C to 5°C per minute. When the maximum temperature is reached, this is held for 0.5 to 2 hours. Preferably, the sintering is performed in a controlled environment which is typically vacuum or of inert atmosphere.

To reduce the effects of or prevent warping and distortion of the green body 23 a pressure of about 2 to 10 g/cm² is applied uniformly to a surface of the green

body 23 during the sintering process. This pressure is achieved by placing a flat ceramic plate having a predetermined weight so as to produce the required amount of pressure on the surface of the green body 23. In this embodiment, the plate has a weight of 100 to 200 grams to produce a direct pressure of approximately 4.5 to 9.0 g/cm². It will be apparent that the amount of pressure to be applied varies since different types of metal components have different characteristics. Preferably, the pressure is maintained throughout the entire sintering process which will alleviate warping of the green body 23.

Figure 3 shows a sintered double layer plate 24 produced in accordance with the method proposed in Figure 1. Figure 4 is a microstructure view of the double layer plate 24 of Figure 3 which illustrates a chemical bonding boundary between the base layer (powder A including Fe) and the top layer (powder B including Ni) which have been bonded together directly without using an intermediate gradient zone. Figure 5 is a microstructure view of another double layer plate formed from Fe powder and 17-4 PH powder. Figures 5a and 5b show microstructure views of further double layer plates formed from M2 (commercial tool steel) and Fe, and M2 and Ni respectively. Please note that the microstructure drawings illustrated herein portray photographs taken on the respective microstructures in order to permit satisfactory reproduction which would not be possible if the actual photographs are used. However, due to the difficulty of illustrating such stipple rendered images, the effect of the drawings may not be as good as the actual photographs.

The application of a suitable amount of pressure on the green body 23 during sintering is unconventional since in a traditional sintering process of the green body without an intermediate gradient zone, the green body 23 will distort during sintering. However, the inventors realised that applying an appropriate amount of pressure actually helps to reduce or prevent warpage of the green body 23 when the two powders A and B are sintered together without an intermediate gradient zone.

In another variation, a ceramic plate 50 is supported at four corners by four members 51 formed from green bodies of powder A or B, as illustrated in Figure 6, so that the plate 50 is spaced from the green body or compact 23 by about 50 to 100 microns during sintering. In this case, the ceramic plate 50 is arranged to apply a pressure of more than 10 g/cm^2 on the top surface of the compact 23 when the green body 23 warps during sintering so that the pressure controls the distortion of the green body 23.

Although the embodiment describes forming the green compact 23 using die pressing (using a die set 20), alternative one step shaping techniques may be used such as tape casting or powder rolling which is preferred for mass producing double layer plates or parts.

Figure 7 shows a tape casting apparatus for forming a double layer green compact according to another embodiment of the present invention. The tape casting apparatus 40 comprises two pairs of "doctor blades" 42,44, reservoirs A and B, and a carrier tape 46 which moves from right to left as shown by the

arrow X. Similar to the first embodiment, metal powders A and B are separately mixed with polymer binders to reduce the shrinkage difference between the two metal powders. In addition, each metal powder is further mixed with solvent and a small amount of corrosion inhibitor to minimise corrosion of the double layer component when fabricated to form a slurry. The slurry can be formulated using commercial standard formulation such as 75-80.32% of metal powders A or B; 0.4% of Menhaden fish oil, brown Z-3; 7.23% of Xylenes; 95% of Ethyl alcohol; 7.23% denatured; 2.41% of Butylbenzyl phthalate, S-160; and 2.41% of Poly(vinyl butyral) grade B-98.

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Similar to the first embodiment, a powder binder is also mixed in the composition to minimise the mismatch of the shrinkage difference due to the different materials. The first slurry 48 comprising powder A, which is the base layer, is received in the reservoir A and the second slurry 49 comprising powder B, being the top layer, is received in the reservoir B. As the first slurry 48 is dispensed from the reservoir A due to the relative carrier tape motion, the first pair of doctor blades 42 "shears" or spreads the moving slurry 48 evenly to form the base layer. As the base layer reaches the second reservoir B, the second slurry 49 comprising powder B is spread on top of the base layer with the help of the second pair of doctor blades 44 to form a double layer slurry. The double layer slurry is then dried typically by infra-red lamps mounted along the moving carrier tape after the second pair of doctor blades 44. After drying, this forms a green compact having sufficient green strength for further handling before the sintering process.

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Typically, the green compact is first cut into the desired shape and then debinded and sintered to form the double layer plate. The sintering process is similar to what has been described in the first embodiment, i.e. pressure is applied on a surface of the green compact, to prevent warping or distortion.

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It will be apparent that other one-step shaping technique is similarly applicable, such as powder rolling.

Using the described embodiments, the present invention is able to overcome
10 the different properties between the two metal powders for example, melting temperature difference and shrinkage difference, to produce a double layer plate which does not exhibit the effects of distortion or warping.

The described embodiment should not be construed as limitative. For example,
15 the preferred embodiment describes mixing the two metal powders separately with different amounts of powder binders, but this may not be absolutely necessary since it may be possible to mix one of the two metal powders with binder powder to change the shrinkage characteristics of one and still reduce the shrinkage difference between the two metal powders.

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In addition, if powder B is required to be coated also on the other side of the base layer (powder A), then a layer of the powder mixture containing powder B is first arranged on the base die 21 prior to depositing the powder mixture containing powder A. After the powder mixture containing powder A is applied

on top of the powder B layer, a further coating layer of powder B is applied on top of powder A to form another coating.

Having now fully described the invention, it should be apparent to one of
5 ordinary skill in the art that many modifications can be made hereto without departing from the scope as claimed.

CLAIMS

1. A method of bonding two metal powder components having different shrinkage factors, the method comprising the steps of:
 - 5 i. mixing one of the powder components with a powder binder to reduce the shrinkage difference between the powder components, thereby forming a powder component mixture,
 - ii. forming a green compact from the powder component mixture and the other metal powder component,
 - 10 iii. sintering the compact to form a permanent bond between the two powder components, and
 - iv. applying pressure on a surface of the compact during the sintering step (iii).
- 15 2. A method according to claim 1, further comprising mixing the other metal powder component with powder binder before the compacting step (ii).
3. A method according to claim 2, wherein one of the metal powder is mixed with three to five weight % of powder binder.
- 20 4. A method according to claim 2, wherein one of the metal powder is mixed with five to fifteen weight % of powder binder.

5. A method according to any one of the preceding claims, further comprising a step of removing the powder binder in a debinding furnace prior to the sintering step.
- 5 6. A method according to claim 1 to 4, wherein the powder binder is removed in a sintering furnace followed by the sintering step.
7. A method according to any one of the preceding claims, wherein the green compact is formed in a die.
- 10 8. A method according to claim 7, further comprising the steps of arranging one of the powder component mixtures in the die as a base layer, arranging the other powder component mixture on top of the base layer; and
15 compressing the powder component mixtures together to form a desired shape of the compact.
9. A method according to any one of the preceding claims, wherein the pressure applied on the surface of the compact during the sintering step
20 is between 2 g/cm^2 and 10 g/cm^2 .
10. A method according to any one of claims 1 to 8, wherein the pressure applied on the surface of the compact during the sintering step is more than 10 g/cm^2 .

11. A method according to claim 9 or 10, wherein the pressure is produced by a ceramic plate.
12. A method according to claim 11, wherein the ceramic plate is placed
5 directly on the surface of the compact during the sintering step.
13. A method according to claim 11, wherein the ceramic plate is spaced from the compact.
- 10 14. A method according to claim 13, wherein the space between the plate and the compact is 50 to 100 microns.
15. A method according to any one of claims 1 to 6, wherein the green compact is formed by tape casting.
- 15 16. A method according to claim 15, further comprising the step of mixing the powder component mixtures with a solvent and polymer binder to form respective slurry mixtures prior to the compacting step.
- 20 17. A method according to claim 16, further comprising the step of layering one slurry mixture on top of the other to form a double layer slurry.
18. A method according to claim 17, further comprising the step of heating the double layer slurry to form the compact.

19. A method according to any one of claims 1 to 6, wherein the compact is formed by powder rolling.
20. A metal part produced using the method according to any one of the preceding claims.
21. A double layer plate produced using the method according to any one of claims 1 to 19.
22. A method of preparing a green compact from two metal powder components having different shrinkage factors, the method comprising the steps of:
- i. mixing at least one powder component with a powder binder to reduce the shrinkage difference between the two metal powder components, thereby forming at least one powder component mixture; and
 - ii. forming a green compact from the at least one powder component mixture.
23. A method of producing a metal part from a green compact formed from two metal powder components having different shrinkage factors with at least one of the powder component being mixed with a powder binder to reduce the shrinkage difference between the two metal powder components, the method comprising the steps of:

- i. sintering the green compact to form a permanent bond between the two powder components; and
- ii. applying pressure on a surface of the green compact during the sintering step (i).