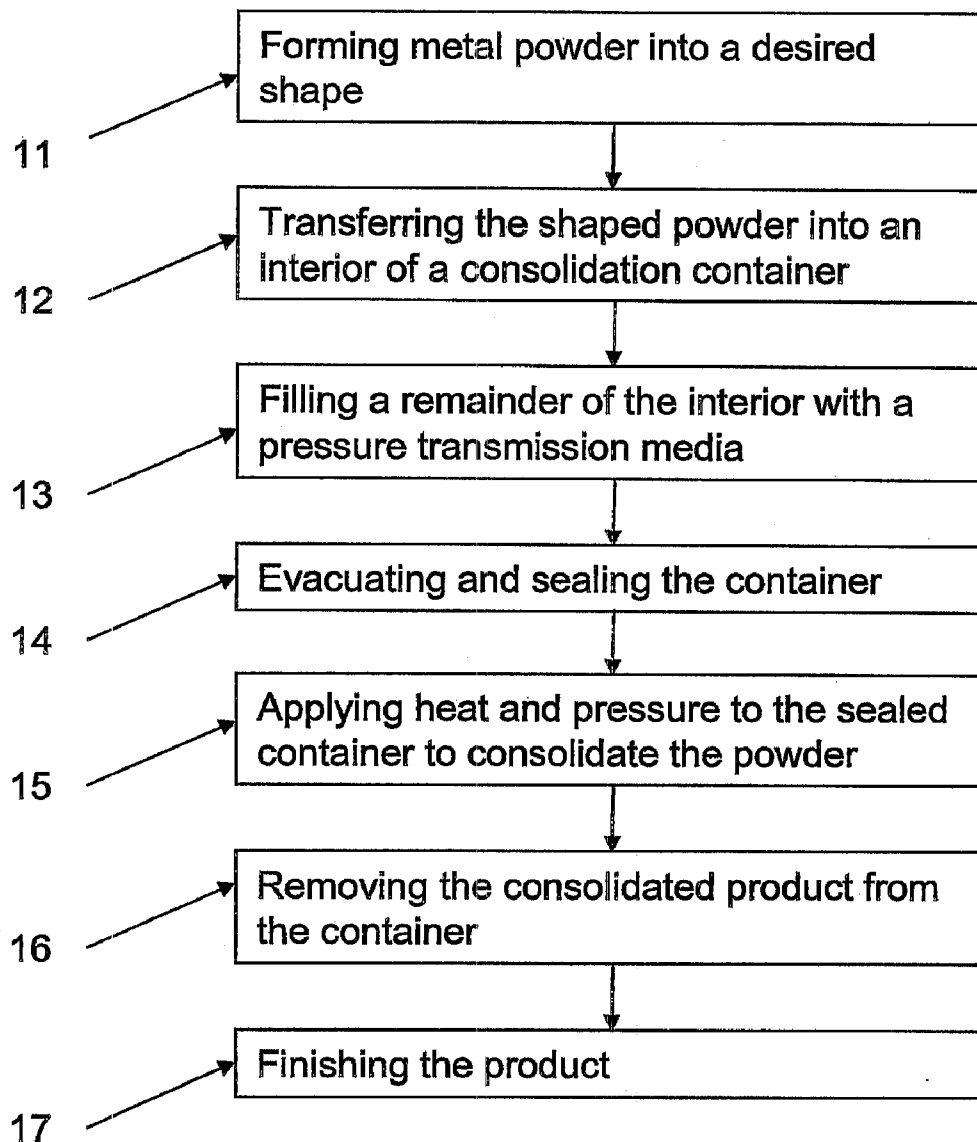




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(19) **United States**(12) **Patent Application Publication****Bono et al.**(10) **Pub. No.: US 2013/0039799 A1**(43) **Pub. Date: Feb. 14, 2013**(54) **METHOD OF MAKING NEAR-NET SHAPES
FROM POWDERED METALS****Publication Classification**(75) Inventors: **Eric S. Bono**, McDonald, PA (US);
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(US)(51) **Int. Cl.**
B22F 3/12 (2006.01)
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B22F 3/15 (2006.01)(73) Assignee: **SUMMIT MATERIALS, LLC**,
McDonald, PA (US)(52) **U.S. Cl.** **419/38; 419/66**(21) Appl. No.: **13/569,222**(57) **ABSTRACT**(22) Filed: **Aug. 8, 2012****Related U.S. Application Data**(60) Provisional application No. 61/521,785, filed on Aug.
10, 2011.

A method of manufacturing a product includes forming a metal powder into a desired shape, transferring the formed metal powder and pressure transmission media into a container, and applying heat and pressure to the container to form a consolidated product from the formed metal powder.



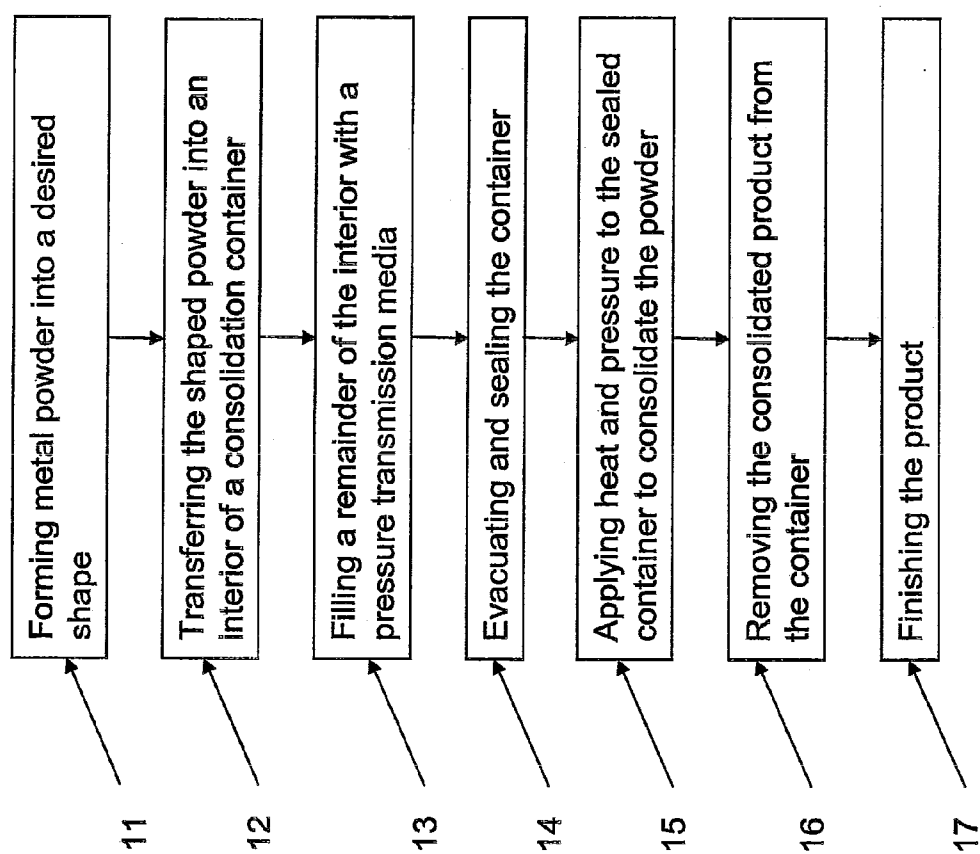


FIG. 1

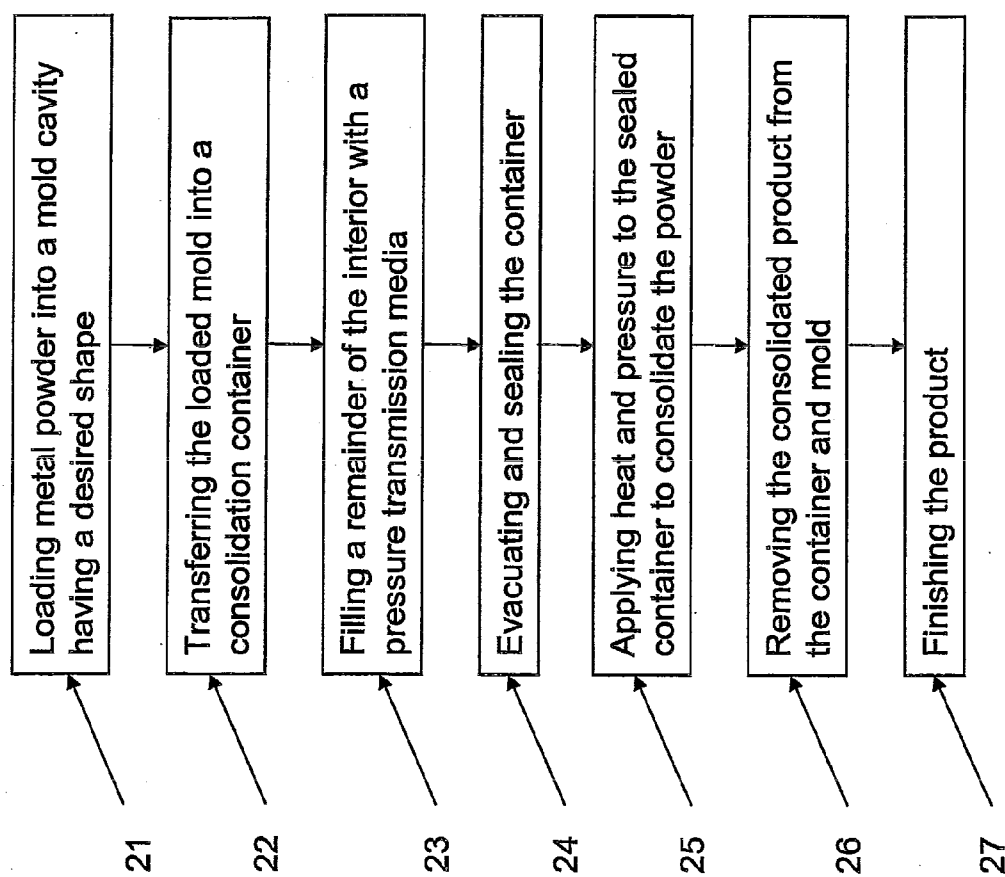


FIG. 2

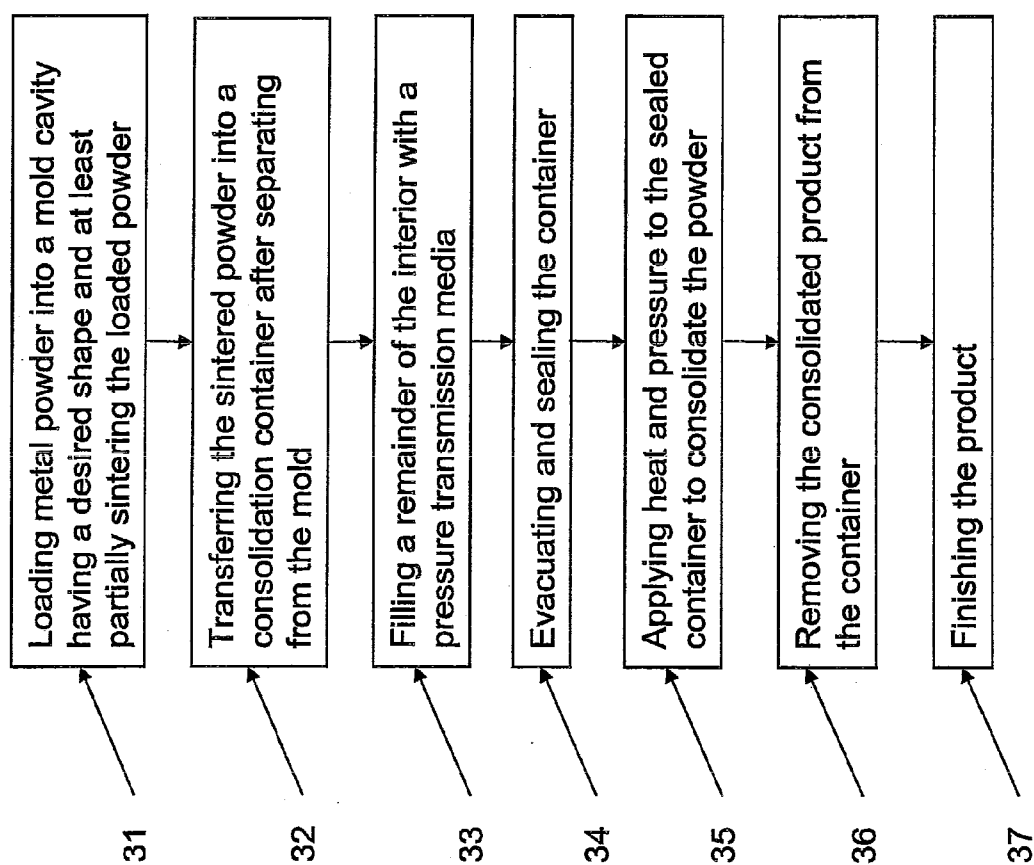


FIG. 3



FIG. 4

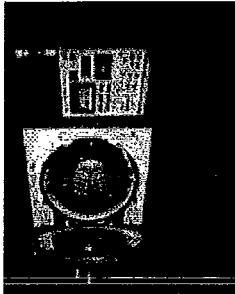


FIG. 6

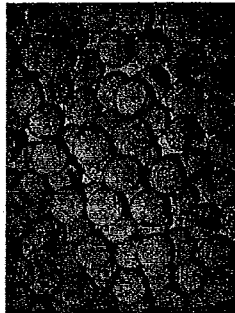


FIG. 7

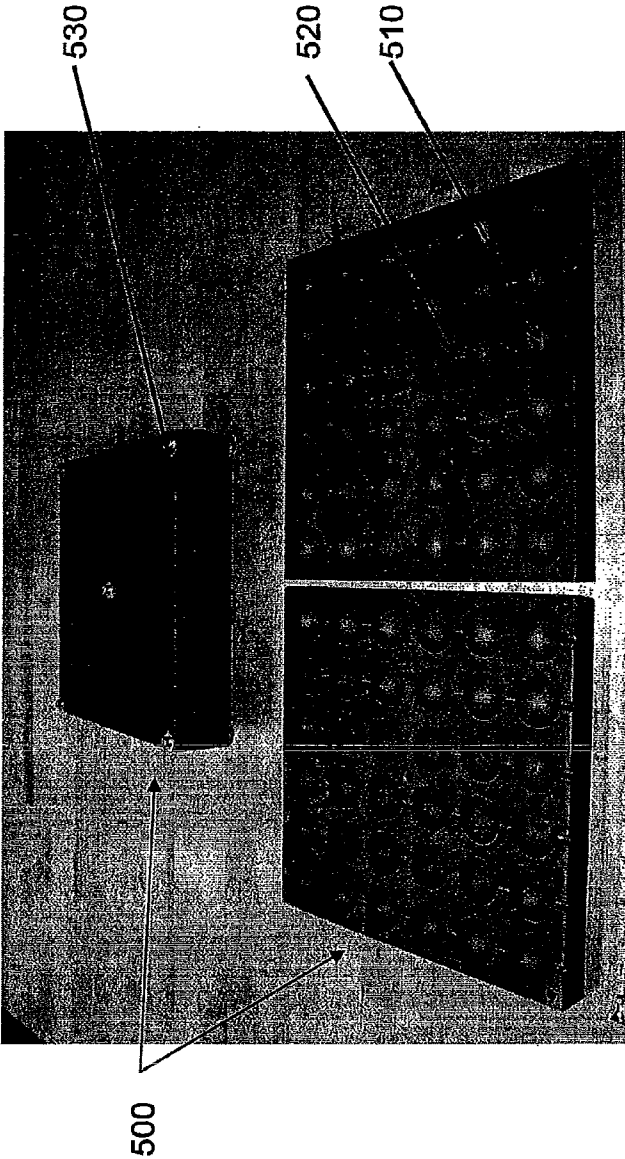


FIG. 5

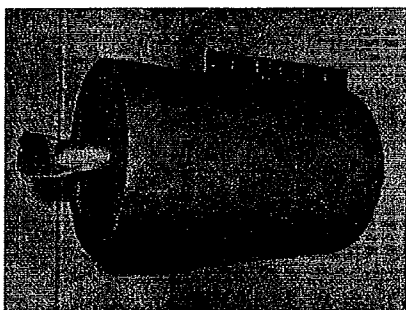


FIG. 9

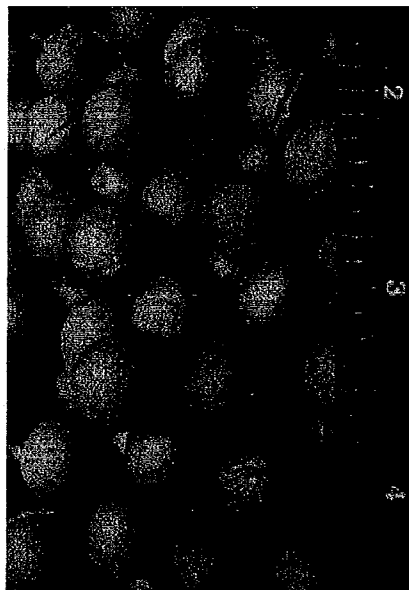


FIG. 11

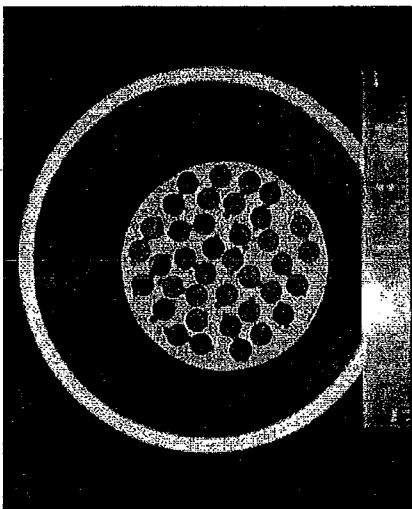


FIG. 8

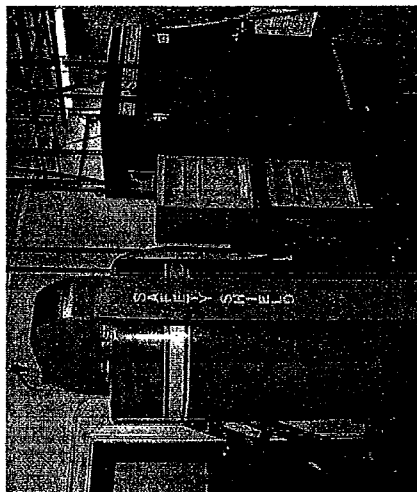


FIG. 10

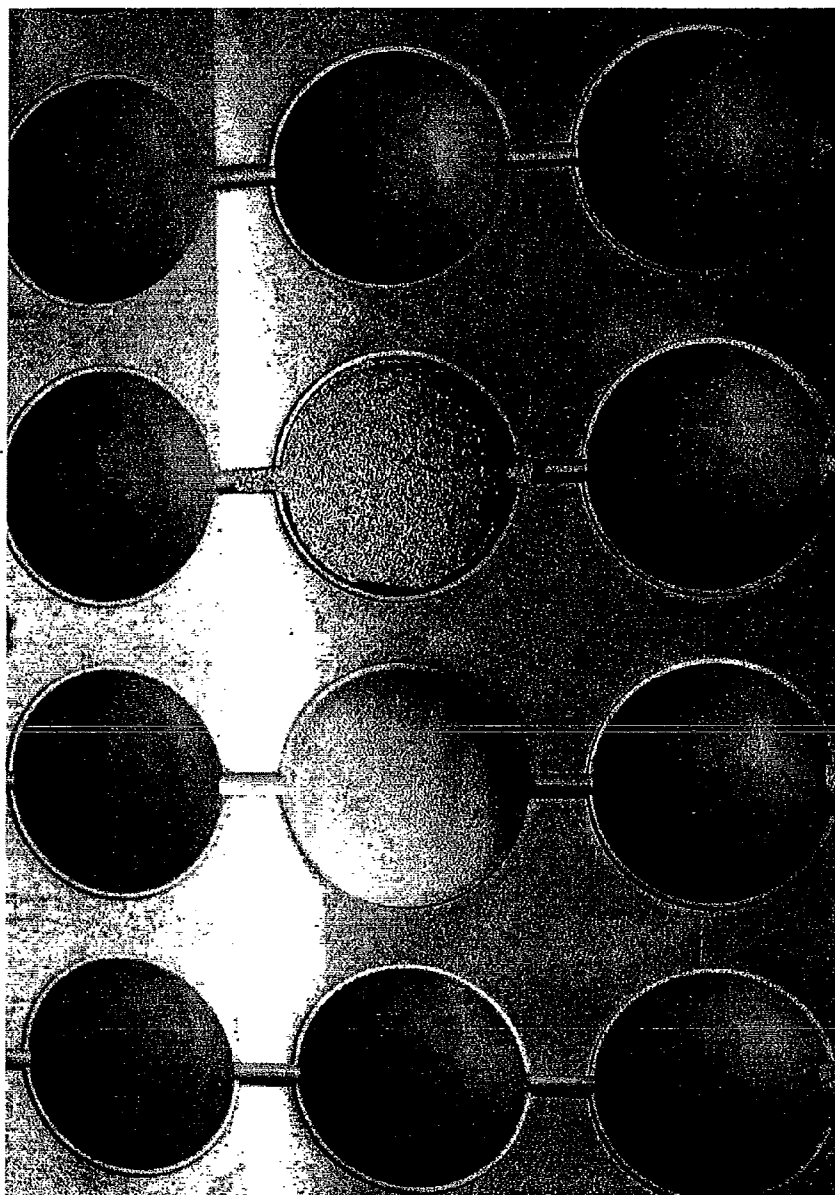


FIG. 12

METHOD OF MAKING NEAR-NET SHAPES FROM POWDERED METALS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from U.S. Provisional Patent Application No. 61/521,784, filed Aug. 10, 2011, which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to methods of manufacturing products from metal powders, and preferably to methods of manufacturing near-net-shape products.

[0004] 2. Description of Related Art

[0005] Conventionally, several manufacturing processes exist for so-called “near-net shape” or “net-shape” processing including direct metal deposition, closed-die forging, investment casting, metal injection molding, press and sinter powder metallurgy, and extrusion.

[0006] Direct metal deposition is used to form metal parts by depositing metal powders using directed energy melting. This manufacturing practice has several inherent disadvantages including difficulty in processing materials that are difficult to weld, size limitations imposed by a size of a given machine’s working chamber, inadequate as-processed material properties, and poor as-processed surface finishes.

[0007] Forgings can be segmented into two broad classes: open and closed-die. Open die forgings are used for small volume needs of demanding components such as those used in aerospace or the oil and gas industries. Once an ingot is forged, the material properties are elevated to acceptable levels by the thermomechanical working of the ingot. The necessary machining, however, often necessitates that over 80% of the forging be removed to create the final component geometry. Closed-die forging, on the other hand, results in near-final geometry, but the tooling costs are often prohibitive except in very high volume part count situations, and delivery of such tooling can often exceed twelve months.

[0008] Investment castings, or “lost wax” castings, offer great potential for geometric accuracies, but the material properties that are produced can be unacceptable for demanding applications such as in aerospace, oil and gas, and chemical processing. These products suffer from two main issues. First, refractory inclusions from the mold may find their way into the final component, thus creating fatal fatigue initiation sites. Secondly, internal porosity is common in castings and can significantly lower material property values below acceptable limits.

[0009] Metal injection molding (MIM) offers good geometry control for small-scale components. A major barrier to MIM acceptance is the complex tooling that needs to be designed and produced. It is both difficult to predict the size of the tooling and extremely expensive to manufacture. The process has inherent size limitations that limit the maximum practical size on the order of only a few pounds. In addition, MIM typically requires the use of very fine (<45 μm) powder which can be very expensive for specialty metals.

[0010] Press and sinter powder metallurgy (PM) has been around for decades in widespread use where material properties aren’t critical. In industries such as automotive where a fully dense part is not required and cost is the main driving factor, PM has advantages over other processing routes for

large volume production. Processing high grade alloys such as gas atomized titanium or nickel-base superalloys is not done in practice, however, due to the inability to press to fully dense components and ensure product integrity.

[0011] Each of these processes has inherent advantages and disadvantages. However, there is a need to manufacture components with material properties essentially equivalent to wrought processed materials such as is found in forged products while maintaining tolerances on par with investment cast products. Also, there is a need to process non-weldable materials and large geometries and include features that are non-machinable.

SUMMARY OF THE INVENTION

[0012] It is an object of the present invention to provide a method of manufacturing products that overcomes one or more problems of the prior art.

[0013] It is another object of the present invention to provide a manufacturing process that allows for close tolerance components to be produced.

[0014] It is yet another object of the present invention to provide material properties essentially equivalent to wrought processed material.

[0015] Another object of the present invention is to provide a process that is optimized for a low density, tough, high strength, corrosion resistant materials.

[0016] Yet another object of the present invention is to provide a manufacturing process that is robust enough to produce a fully dense final product.

[0017] Yet another object of the present invention is to provide a manufacturing process that is robust enough to produce a fully dense final product.

[0018] A further object of the present invention is to provide a manufacturing process that uses sintered or non-sintered starting components.

[0019] It is another object of the present invention to provide a manufacturing process capable of producing complex shaped components at an affordable cost that have material properties similar to forgings while maintaining tolerance levels often found in castings.

[0020] It is an additional object of the present invention to bring freedom to engineers to optimize component designs with less concern for the manufacturability, cost, and lead time of the final component.

[0021] It is a further object of the present invention to enable an end customer to provide a manufacturer with an electronic model of a part they designed with minimal design iterations needed to ensure part manufacturability.

[0022] It is yet a further object of the present invention to provide a manufacturing process that is environmentally advantageous

[0023] It is yet a further object of the present invention to provide a manufacturing process with extreme reductions in raw material usage, machining time, energy, and/or coolant usage.

[0024] It is another object of the present invention to provide a process that combines the ability to manufacture large-scale complex geometries with non-machinable features out of non-weldable materials with material properties similar to wrought products while offering tolerances typically associated with cast components.

[0025] It would be understood that these and other objects of the present invention are attainable with reference the drawings and detailed description, as well as with the addi-

tional understanding of those skilled in the art, by a method of manufacturing a product according to the present invention, including: forming a metal powder into a desired shape; transferring the formed metal powder and pressure transmission media into a container; and applying heat and pressure to the container to form a consolidated product from the formed metal powder.

[0026] A method of preparing a metal powder for consolidation according to the present invention includes: forming a metal powder into a desired shape; transferring the formed metal powder and pressure transmission media into a container; and applying a vacuum to and sealing the container, which may thereafter consolidated using heat and pressure.

[0027] The metal powder may include an alloy or intermetallic compound.

[0028] Forming the metal powder into the desired shape may include loading the metal powder into a mold having at least one cavity therein that is shaped to correspond to a near final shape of the product. The formed metal powder may be transferred into the container with the mold. Alternatively, the formed metal powder may be at least partially sintered and separated from the mold before being transferred into the container. The method may include repeating the method while reusing the mold.

[0029] A composition of the metal powder may include at least one of Ni and Ti. The composition of the metal powder may include 58-62 wt % Ni and 38-42 wt % Ti. The composition of the metal powder further may include up to 5% of other elements.

[0030] The pressure transmission media may include at least one of alumina and zircon sand.

[0031] Between the steps of transferring the formed metal powder and pressure transmission media into the container and applying heat and pressure to the container, the method may include: sealing a lid onto an opening of the container, the lid having a vacuum port therein; applying a vacuum via the vacuum port to evacuate the interior of the container; and sealing the vacuum port while under vacuum to provide an sealed evacuated container.

[0032] Applying heat and pressure to the container may include hot isostatically pressing the container.

[0033] The method may further include finishing the consolidated product to form the final shape of the product.

[0034] Forming the metal powder into the desired shape may include forming the powder via an additive manufacturing process. The additive manufacturing process may include cold spray, laser additive manufacturing or electron beam additive manufacturing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] FIG. 1 is a flow chart of a method of manufacturing a product according to an embodiment of the present invention.

[0036] FIG. 2 is a flow chart of a method of manufacturing a product according to another embodiment of the present invention.

[0037] FIG. 3 is a flow chart of a method of manufacturing a product according to yet another embodiment of the present invention.

[0038] FIG. 4 represents a metal powder according to an example of the present invention.

[0039] FIG. 5 represents a mold according to an example of the present invention.

[0040] FIG. 6 represents a vacuum sintering apparatus according to an example of the present invention.

[0041] FIG. 7 represents a sintered powder pre-form according to an example of the present invention.

[0042] FIG. 8 represents sintered spheres in a consolidation container according to an example of the present invention.

[0043] FIG. 9 represents an evacuated and sealed container according to an example of the present invention.

[0044] FIG. 10 represents a HIP apparatus according to an example of the present invention.

[0045] FIG. 11 represents fully dense spheres according to an example of the present invention.

[0046] FIG. 12 shows a comparison of the size and shape of the sintered spheres of FIG. 7 (on the left) with the fully dense spheres of FIG. 11 (on the right).

BRIEF DESCRIPTION OF THE INVENTION

[0047] As shown in FIG. 1, a method of manufacturing a product according to an embodiment of the present invention may include a first step **11** of a forming metal powder into a desired shape. The metal powder may include pure metal powder, alloyed metal powder and intermetallic compounds. Although not limited thereto, particles of the metal powder are preferably generally spherical. The metal powder may be formed by any suitable method including, but not limited to gas atomization.

[0048] In one exemplary embodiment, the metal powder may include, for example, at least one Fe, Ni, Ti, preferably both Ni and Ti, and more preferably includes 58-62 wt % Ni, 38-42 wt % Ti, optionally up to 5% of other elements. The composition of the metal powder may be selected to have shape memory properties. The metal powder may also be composed of a titanium-based or a nickel-base superalloy.

[0049] The forming may include any method by which the metal powder is formed into the desired shape such that the desired shape can be maintained during a subsequent transfer into a container for consolidation. For example, the metal powder may be loaded into a mold and maintained in the desired shape using a mold. Alternatively, the metal powder may be loaded into a mold and then maintained in the desired shape using another technique, such as by at least partially sintering the loaded powder. In yet another alternative, the metal powder may be formed into the desired shape by an additive manufacturing process, such as by cold spray, laser additive machining or electron beam additive manufacturing. Preferably, the molds or additive manufacturing processes are designed to ensure that the final product after finishing will be within design tolerances. Due to the flexibility of ways of forming the metal powder into a desired shape, design changes during production that were conventionally prohibitive due to the expense of altering a forging die can be done on the fly for very little cost and time.

[0050] The shape of the formed metal powder is not limited to any particular shape. Preferably, the metal powder is formed into a "near-net-shape" that corresponds to a near final shape of a product. As a result, the consolidated product could be easily finished into the final shape. In one aspect, the metal powder may be shaped into complex geometries and/or the shape may include features that are non-machinable or not easily machinable, such as internal cooling channels or drastic cutbacks, thus allowing design engineers the freedom to create optimal design without worrying about manufacturing

limitations. In selected embodiments, the size of the formed metal powder ranges from less than 100 grams to several thousand pounds.

[0051] In another aspect, the metal powder may be formed into a shape that corresponds to shape of a welded product, and the metal powder may be composed of a non-weldable material or a material that is difficult to weld. As a result, the present invention enables for producing a combination of shape and material properties not available by conventional welding methods.

[0052] The method of manufacturing a product may include a second step **12** of transferring the shaped powder into an interior of a consolidation container, such as a steel container having one opening therein. The shaped powder product may be transferred together with one or more other shaped powder products for simultaneous consolidation.

[0053] The method of manufacturing a product may include a third step **13** of filling a remainder of the interior of the consolidation container with a pressure transmission media. The pressure transmission media is used to transfer the consolidation pressure during a consolidation step from the consolidation can to one or more shaped powder products in the interior of the consolidation container to provide a fully or near-fully dense product. Although not limited thereto, alumina and zircon sand may be used as the pressure transmission media.

[0054] The shaped powder products are preferably essentially encapsulated in the pressure transmission media with adequate spacing between components and the consolidation container to prohibit touching. Preferred spacing between the shaped powder products is on the order of 2 centimeters. For complex components, it is preferred to fully fill internal channels to maintain geometric integrity of the shaped powder products throughout the consolidation process.

[0055] The method of manufacturing a product may include a fourth step **14** of evacuating and sealing the consolidation container. In one example, the consolidation container includes one opening therein. A lid having a vacuum port may then be sealed onto the opening, such as by welding. A vacuum may then be applied via the vacuum port to evacuate the interior of the consolidation container. Heat may be applied, for example by heat tape or by housing the consolidation container in a furnace or oven, to the exterior of the container to aid in vacuum process. Then, the vacuum port may be sealed while under vacuum to provide an evacuated and sealed container.

[0056] The method of manufacturing a product may include a fifth step **15** of applying heat and pressure to the sealed container to consolidate the powder. This may include, for example, a Hot Isostatic Pressing (HIP) process. In one aspect, the fourth step **14** of evacuating and sealing the consolidation container may be performed at a high quality such that the evacuated and sealed container may be transferred to another facility that includes a HIP apparatus.

[0057] The method of manufacturing a product may include a sixth step **16** of removing the consolidated product from the container. This step may be preformed by, for example, machining, or cutting to open the container, after which the pressure transmission media may be separated from the consolidated product and the consolidated product may be cleaned to completely remove the pressure transmission media. This cleaning can be done in a variety of ways, such as by machining, sand blasting, wire brushing and/or media tumbling. At this time, the pressure transmission media

may also be recycled for future use as a pressure transmission media or otherwise, to control costs and improve the environmental friendliness of the process.

[0058] The method of manufacturing a product may include a sixth step **17** of finishing the product. As a result of the preceding steps, the consolidated product may be formed in a near-net-shape, thereby eliminating extensive machining and associated material losses associated with conventional methods. However, the product may also have an irregular surface due to the consolidation process. Therefore, limiting machining may be desired to finished the consolidated product to its final intended shape. The various ways of finishing a near-net-shaped product are well-known to those skilled in the art.

[0059] As shown in FIG. 2, an embodiment of the method of manufacturing a product may include a first step **21** of loading metal powder into at least one mold cavity having a desired shape and a second step **22** of transferring the loaded mold into a consolidation container. The shape of the mold cavity corresponds to the desired shape of the formed metal powder as explained with reference to FIG. 1. Because the mold is loaded into the consolidation container, the mold may be formed of a material able to withstand the applied temperature and pressure of the consolidation step, yet also inexpensive enough to be discarded after one or a few uses. One advantage of the embodiment of FIG. 2 is that the shape of the cavity, and thus final product, are not limited to non-destructive removal from the mold because the consolidated product may be removed from the mold by destructive means.

[0060] The method of manufacturing a product may include a third step **23** of filling a remainder to the interior with a pressure transmission media, a fourth step **24** of evacuating and sealing the container, a fifth step **25** of applying heat and pressure to the sealed container to consolidate the powder and a sixth step **26** of removing the consolidated product from the container and mold and a seventh step **37** of finishing the consolidated product, each of which have been previously explained above, except unlike FIG. 1, the sixth step **36** requires removing the consolidate product from the mold.

[0061] As shown in FIG. 3, an embodiment of the method of manufacturing a product may include a first step **31** of loading metal powder into at least one mold cavity having a desired shape and at least partially sintering the loaded powder. The shape of the mold cavity corresponds to the desired shape of the formed metal powder as explained with reference to FIGS. 1 and 2. The mold may be made of any suitable material, including, but not limited to, ceramics, graphite and steels, and the mold may include a plurality of mold segments that are assembled together to form the complete mold. The mold segments may be assembled and joined together by a restraint system such as, for example, screws, pins, bands, latches, or clasps. After the mold is assembled, the metal powder is loaded into the mold.

[0062] The powder may be loaded into the mold cavity by any suitable process, including, but not limited to, gravity feed with or without vacuum conditions. The powder may be loaded through one or more orifices in the mold. Multiple cavities may be housed in a single mold, and multiple cavities may be connected together by runners that allow for powder to flow between the cavities to fully fill each cavity. The mold may be vibrated, such as by an automatic or manual external source, to help ensure complete filling of the mold cavity. It is preferred but not necessary to calculate the volume of the cavities and subsequently the necessary weight of powder needed to fill the cavities as a quality check that the proper amount of power has been loaded into the mold.

[0063] Once the mold is fully loaded, the orifices in the mold may be plugged to ensure that the loaded powder does not spill out of the mold. The plugged mold may then be transferred to a sintering furnace to maintain the metal powder in the desired shape after separating the sintered powder from the mold.

[0064] The method of manufacturing a product may include a second step 32 of transferring the sintered powder into a consolidation container after the sintered powder is separated from the mold. Preferably, the mold includes a plurality of mold segments that were assembled together to form the complete mold and are now disassembled to separate the sintered powder from the mold. Preferably, the mold is designed and manufactured to be reusable, such that the mold can be reassembled together and loaded with additional metal powder to repeat the method. In this case, the cavity and final desired product are preferably shaped to allow for easy removal of the sintered product from the mold. For example, the walls of the cavity are preferably tapered towards each other in a depth direction of the cavity in each mold segment.

[0065] The method of manufacturing a product may include a third step 33 of filling a remainder to the interior with a pressure transmission media. Similar to above description of FIG. 1, the loaded molds may be spaced apart by the pressure transmission media in the consolidation container to prohibit touching and allow for consolidation to fully occur.

[0066] The method of manufacturing a product may include a fourth step 34 of evacuating and sealing the container, a fifth step 35 of applying heat and pressure to the sealed container to consolidate the powder and a sixth step 36 of removing the consolidated product from the container and a seventh step 37 of finishing the consolidated product, each of which have been previously explained above, except unlike FIG. 2, the sixth step 36 does not necessitate removing the consolidate product from the mold.

[0067] FIGS. 4-12 represent an example of a method of the present invention used to form a near net shape ball bearing formed from NITINOL powder. As shown in FIG. 4, a spherical pre-alloyed NITINOL powder was obtained and loaded into a mold 500, including cavities 510, runners 520 and orifices 530, as shown in FIG. 5. The loaded mold was then vacuum-sintered as represented by FIG. 6, resulting in the sintered spheres shown in FIG. 7. The sintered spheres with pressure transmission media were then transferred to a consolidation can as shown in FIG. 8. After a lid having a stem was welded onto the opening of the can, a vacuum was applied to evacuate the interior of the can, and the stem of the lid was sealed as shown in FIG. 9. Then, as shown in FIG. 10, the can was transferred to a HIP apparatus where the sintered spheres were consolidated under high temperature and pressure, resulting in fully dense spheres shown in FIG. 11. FIG. 12 shows a comparison of the size and shape of the sintered spheres of FIG. 7 (on the left) with the fully dense spheres of FIG. 11 (on the right).

[0068] Accordingly, the method resulted in fully dense ball bearings that could be later finished to result in close tolerance components with properties essentially equivalent to conventionally-produced wrought and machined ball bearings.

[0069] Although the invention has been described in detail for the purpose of illustration based on what is currently considered to be the most practical and preferred embodiments, it is to be understood that such detail is solely for that purpose and that the invention is not limited to the disclosed

embodiments but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. For example, it is to be understood that the present invention contemplates that, to the extent possible, one or more features of any embodiment can be combined with one or more features of any other embodiment.

What is claimed is:

1. A method of manufacturing a product, comprising: forming a metal powder into a desired shape; transferring the formed metal powder and pressure transmission media into a container; and applying heat and pressure to the container to form a consolidated product from the formed metal powder.
2. The method of claim 1, wherein the metal powder includes an alloy or intermetallic compound.
3. The method of claim 1, wherein forming the metal powder into the desired shape includes loading the metal powder into a mold having at least one cavity therein that is shaped to correspond to a near final shape of the product.
4. The method of claim 3, wherein the formed metal powder is transferred into the container with the mold.
5. The method of claim 3, wherein the formed metal powder is at least partially sintered and separated from the mold before being transferred into the container.
6. The method of claim 5, further comprising repeating the method while reusing the mold.
7. The method of claim 1, wherein a composition of the metal powder includes at least one of Ni and Ti.
8. The method of claim 7, wherein a composition of the metal powder includes 58-62 wt % Ni and 38-42 wt % Ti.
9. The method of claim 8, wherein the composition of the metal powder further includes up to 5% of other elements.
10. The method of claim 1, wherein the pressure transmission media includes at least one of alumina and zircon sand.
11. The method of claim 1, further comprising, between the steps of transferring the formed metal powder and pressure transmission media into the container and applying heat and pressure to the container: sealing a lid onto an opening of the container, the lid having a vacuum port therein; applying a vacuum via the vacuum port to evacuate the interior of the container; and sealing the vacuum port while under vacuum to provide an sealed evacuated container.
12. The method of claim 1, wherein applying heat and pressure to the container includes hot isostatically pressing the container.
13. The method of claim 1, further comprising finishing the consolidated product to form the final shape of the product.
14. The method of claim 1, wherein forming the metal powder into the desired shape includes forming the powder via an additive manufacturing process.
15. The method of claim 14, wherein the additive manufacturing process includes cold or thermal spray, or directed energy additive manufacturing.
16. A method of preparing a metal powder for consolidation, comprising: forming a metal powder into a desired shape; transferring the formed metal powder and pressure transmission media into a container; and applying a vacuum to and sealing the container.

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