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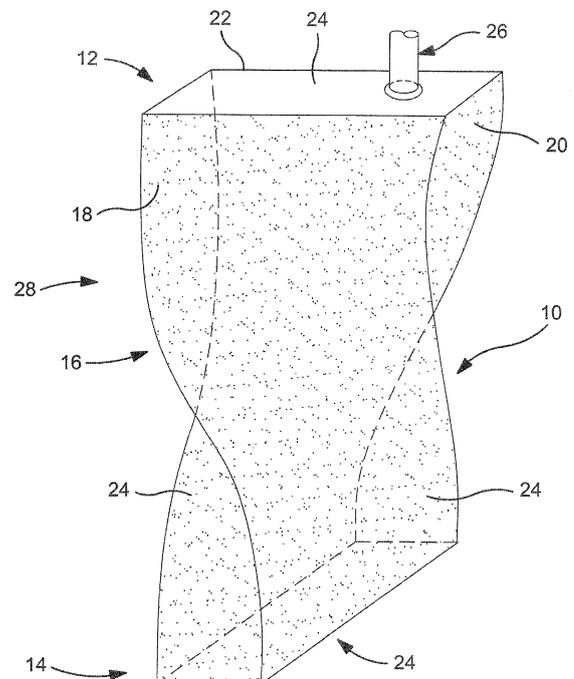
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(54) **DYNAMIC BONDING OF POWDER METALLURGY MATERIALS**

(57) A dynamic compaction process comprising providing a container (22; 116) having a non-cylindrical shape; filling said container (22; 116) with a first powder material (18; 110, 114); sealing the container (22; 116) and dynamically compacting said first powder material (18; 110, 114).



**FIG. 1**

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## Description

### BACKGROUND

**[0001]** The present disclosure is directed to the improved process of dynamic bonding to create hybrid powder metallurgy parts.

**[0002]** Advanced aerospace designs continue to challenge materials and materials technology. While powder metallurgy materials offer unique advantages for many aerospace components, they could be further optimized if dissimilar materials could be bonded into a single component.

**[0003]** For example, in gas turbine engines, disks which support turbine blades rotate at high speeds in an elevated temperature environment. The separate portions of the disks are exposed to different operating conditions and temperatures. Thus, different combinations of mechanical properties are required at different locations. The high temperature rim portion has fatigue crack growth resistance and creep resistance, while the highly stressed hub portion has high burst strength at relatively moderate temperatures and fatigue crack growth resistance. The hub portion also has high resistance to low cycle fatigue for long component life.

**[0004]** Because of these differing requirements for the mechanical properties of the separate disk portions, and the extreme temperature gradients along the radius of a turbine disk, a single alloy is not well suited to satisfy the requirements of both the hub and the rim area of a modern turbine disk.

**[0005]** A possible solution is to use a dual alloy disk with different alloys used in the different portions of the disk, depending upon the properties desired. The disk has a joint region in which the different alloys are joined together to form an integral article.

**[0006]** Numerous techniques for fabricating dual alloy disks have been considered, such as fusion welding, inertia welding, diffusion bonding, bi-casting, and hot isostatic pressing which may be employed to consolidate powder used for one portion of a disk, such as the hub, and also to join it to the other portion. Many of these processes have drawbacks, for example, the disadvantage of hot isostatic pressing is that any impurities present at the joint prior to hot isostatic pressing will remain, and may be exacerbated by the lengthy time at elevated temperature and pressure.

**[0007]** Present powder-metallurgical techniques require three to four steps to produce a finished product. For example, producing tungsten requires pressing and pre-sintering, followed by a consolidation sinter and/ or several hot-working steps. Dynamic bonding eliminates the need for large presses and expensive hot-pressing dies. In many instances, actual production time and costs may be reduced.

## SUMMARY

**[0008]** In accordance with the present disclosure, there is provided a dynamic compaction process comprising providing a container having a non-cylindrical shape such as a blade shape; filling the container with a first powder material; sealing the container; and dynamically compacting the first powder material.

**[0009]** In an exemplary embodiment the first powder material comprises a nickel alloy.

**[0010]** In an exemplary embodiment the process further comprises removing unwanted gases by use of a vacuum on the first container subsequent to filling the container.

**[0011]** In an exemplary embodiment forming a component from the preform of the first powder material.

**[0012]** In an exemplary embodiment the component comprises a blade having a tip portion, airfoil portion and root portion formed from the first powder material.

**[0013]** In an exemplary embodiment the process further comprises forming a component precursor from the solid powder metallurgy material; and cutting at least one blade from the component precursor.

**[0014]** In an exemplary embodiment the process further comprises dynamically compacting the first powder material by use of a compaction mat.

**[0015]** In an exemplary embodiment the process the process further comprises aligning the compaction mat at an exterior surface of the container opposite an immovable object.

**[0016]** In an exemplary embodiment the dynamic compaction is initiated by a fuse coupled to the compaction mat proximate a first end of the container.

**[0017]** In an exemplary embodiment the dynamic compaction occurs across the container exterior surface from a first end of the container to a second end of the container.

**[0018]** In accordance with the present disclosure, there is provided an aerospace component comprising a first alloy powder metallurgy material bonded together with dynamic compaction.

**[0019]** In an exemplary embodiment the aerospace component is near net shape.

**[0020]** In an exemplary embodiment the aerospace component is a turbine engine component such as a blade.

**[0021]** In accordance with the present disclosure, there is provided a container for dynamic compaction of an alloy powder metallurgy material, wherein the container has a non-cylindrical shape and is configured to encapsulate the alloy powder metallurgy material.

**[0022]** In an exemplary embodiment the non-cylindrical shape is selected from the group consisting of a blade shape, a vane shape and an airfoil shape.

**[0023]** In an exemplary embodiment container comprises a filling tube configured to receive the alloy powder metallurgy material for insertion into a cavity of the container.

**[0024]** In an exemplary embodiment the filling tube is configured to facilitate evacuation of gases from the cavity via a vacuum on the cavity.

**[0025]** In an exemplary embodiment the container is configured to be sealed from invasive gases.

**[0026]** Other details of the dynamic bonding process are set forth in the following detailed description and the accompanying drawing wherein like reference numerals depict like elements.

#### BRIEF DESCRIPTION OF THE DRAWINGS

##### **[0027]**

FIG. 1 is a schematic representation of a turbine engine component preform to be formed from a powdered material dynamically compacted;

FIG. 2 is a schematic representation of an exemplary embodiment of a turbine engine component preform formed from a powdered material dynamically compacted;

FIG. 3 is a process diagram of an exemplary dynamic compaction process.

#### DETAILED DESCRIPTION

**[0028]** Referring now to FIG. 1, there is illustrated a turbine engine component precursor 10, such as a blade or vane. It is contemplated that other components can be formed with the process, such as shafts, rotors, air-seals and the like. The exemplary turbine engine component precursor 10, when fully manufactured, has a tip portion 12 and a root portion 14 connected by an airfoil portion 16.

**[0029]** The turbine engine component 10 may be formed from a titanium-based alloy or nickel based alloy or a composite of alloys formed together to optimize the material properties of each constituent alloy. In an exemplary embodiment, the tip 12, root 14 and airfoil 16 portions can comprise a first material 18 composition of titanium alloy or nickel alloy powder such as, Ni-Co-Cr-Al superalloy. In alternative embodiments, the tip portion 12 can comprise another second material 20 such as a nickel powder alloy such as, Ni-Co-Cr-Ta superalloy. The first material 18 can comprise properties that are best suited for a particular region of the component 10, such as, the tip 12 or airfoil 16 region of the component 10. The second material 20 can comprise properties that are best suited for another region of the component 10, such as, the root 14. In an exemplary embodiment, the first material 18 can be a lower cost alloy and the second material 20 can be a more expensive alloy, and in exemplary embodiments capable of operating at higher operating temperatures and having superior mechanical properties such as being able to operate under higher stress levels for example creep and stress rupture.

**[0030]** In one alternative, the precursor 10 can be formed by use of dynamic consolidation or compaction

of alloy powder metallurgy material(s), such as a nickel alloy powder. The terms dynamic consolidation and dynamic compaction as well as dynamic bonding can be used interchangeably throughout the description.

**[0031]** The alloy powder is subjected to dynamic compaction. Dynamic compaction is characterized as momentary application of an extremely high pressure. This is contrasted with the compression characteristic of press-sintered and hot-press methods used in other processes, which are conducted at a much lower pressure and are carried out over an extended period of time.

**[0032]** Dynamic compaction is best achieved by shock waves produced by, for example, contact with a shaped explosive charge, or by impact with a high-velocity projectile. The shock waves moving through the powder create pressures that are several times the flow stress of the binding metallic phase, typically several GPa (usually about 2 to 7 GPa.). Consolidation occurs by deformation of the powder particles and extrusion into void spaces between the particles. The material at or near the surface of the particle undergoes temperature pulses that range from microseconds to milliseconds, but these are quickly quenched by heat flow into the bulk of the powder particle. Since the heating is extremely short, it cannot support chemical reaction, melting, or other phase formation processes. Thus, it is possible to essentially preserve the original microstructure of the alloy material interface, with little or no chemical reaction or alloying. Thus, the formation of undesirable phases that can compromise the physical properties of the final compacted shape is avoided.

**[0033]** The precursor 10 can be formed into a generally twisted rectilinear shaped cross section. The shape as shown in FIG. 1, exemplifies a blade or vane. It is contemplated that the precursor 10 can be formed into any variety of shapes, some of which are near net shaped geometry.

**[0034]** The precursor 10 can be formed by filling a non-cylindrical shaped, blade shaped or more appropriately shaped container 22 with the first material 18 powder. Excess air/gases can be evacuated from the container 22.

**[0035]** The container 22 is sealed by mechanical means and/or by welding. The sealed container is then subjected to instantaneous dynamic compaction (i.e., explosion) which applies very high pressure to exterior surfaces 24 of the container 22. The container is collapsed upon the internal powder 18, 20 with the high pressure force to form a solid powder metallurgy preform encased by the container. The container is then removed by conventional machining.

**[0036]** A filling tube 26 is shown and can be substituted by a rigid cover (not shown), or an integral boss welded to the container 22 and an internally fitting plug (not shown) substituted for the filling tube 26. The container can be evacuated of air and other gases. In an exemplary embodiment, a vacuum of  $10^{-6}$  Torr (133  $\mu$ Pa) can be applied to the container to prevent oxidation of the first

powder material 18. The container 22 can be removed from the precursor 10 to form a component 28.

**[0037]** The newly formed component 28 is now ready for subsequent processing, such as, forging and thermal mechanical processes as required to form the final shape of the component 28.

**[0038]** FIG. 2 shows an exemplary embodiment of a turbine engine component precursor 100 formed by a powdered material 110 dynamically compacted to a preform 112. The exemplary embodiment of FIG. 2 shares many similarities to the exemplary embodiment of FIG. 1. The preform 112 is similar to the precursor 10 at FIG. 1, since it can be formed into a solid of virtually any shape formed by use of dynamic consolidation or compaction of alloy powder metallurgy material(s), (i.e., a first alloy 114), such as a nickel alloy powder. The preform 112 in this embodiment, is a blade shape, having a predefined length L. In an exemplary embodiment the predefined length L can be several feet. The thickness of the preform 112 can be on the order of inches (cm) depending on the ultimate size of the turbine engine component precursor 100.

**[0039]** The powdered material 110 can be placed into a container 116 of appropriate size and shape. The container 116 can be sized, such that, the first alloy material 114, or alloy powder metallurgy material(s), can fill the container 116. The container 116 can be a blade shape forming a cavity 118 that is configured to be filled with the alloy material 110. The container 116 includes a first end or cap 120 and a second end or cap 122 opposite the first end 120. The first and second ends 120, 122 enclose the cavity and encapsulate the first alloy material 114.

**[0040]** A tube 124 can be inserted through the second end 122, allowing communication of materials/gases with the cavity 118 and outside the container 116. The cavity 118 of the container 116 can be filled with the alloy powder metallurgy material(s) 114 through the tube 124. In exemplary embodiments, the tube 124 can also facilitate evacuation of the container, removing any unwanted gases, such as, gases that may promote oxidation.

**[0041]** The first end 120, second end 122 and tube 124 can be sealed, such that the container 116 filled with the alloy material 114 is sealed from any invasive gases. The container 116 is sealed by mechanical means or by welding.

**[0042]** A compaction mat 126 can be placed on the container 116 adjacent an exterior surface 128 of the container 116. The compaction mat 126 covers the exterior surface 128 between the first end 120 and second end 122. The container 116 is shown laid on an immovable object 129. The compaction mat 126 as shown, is placed on the exterior surface 128 opposite the immovable object 129. The compaction mat 126 is configured to contain the explosive components that initiate the dynamic compaction. In an exemplary embodiment, the compaction mat 126 can include a composition of fertilizer (ammonium nitrate) and kerosene in the appropriate

proportions to facilitate momentary application of an extremely high pressure. Other forms of explosive materials are also contemplated. A fuse 130 is coupled to the compaction mat 126. In operation the fuse 130 is ignited and a chain reaction of rapid chemical explosion travels across the compaction mat 126 from the first end 120 to the second end 122 along the length L.

**[0043]** The alloy powder material 114 is dynamically compacted to form the preform 112. The container 116 can be removed from the preform 112 to have a newly formed component precursor 100.

**[0044]** The component precursor 100 can be formed as near net shape or cut into blades as shown by the dashed lines D. The newly formed component precursor 100 is now ready for subsequent processing, such as, forging and thermal mechanical processes as required to form the final shape of a component 132, such as shown in dashed lines at FIG. 2.

**[0045]** In an exemplary embodiment, the component precursor 100 can be utilized for high volume production of components 132, such as blades, vanes, airseals and other aerospace components.

**[0046]** FIG. 3 shows an exemplary process embodiment, namely the formation of a powdered material dynamically compacted preform. This exemplary embodiment is similar to the other exemplary embodiments shown in FIG. 1 and FIG. 2.

**[0047]** The first step includes providing a container 200. The component precursor or preform can be formed by dynamic compaction 210 of a first alloy material for the preform. The preform is then processed into a final shape 212.

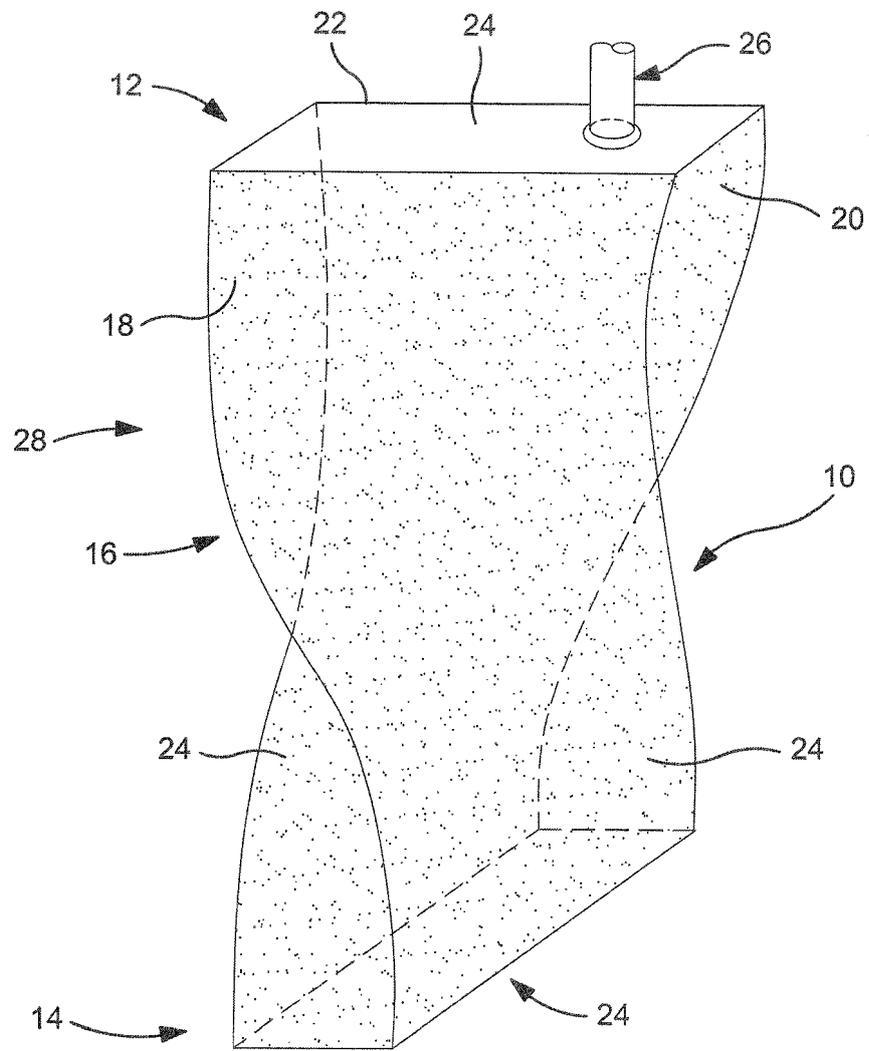
**[0048]** Dynamic compaction provides an alternative method for compaction of powder metallurgy material as compared to conventional methods of compaction, such as, hot isostatic pressing or extrusion. The new method allows for the compaction of materials that previously may not have been capable of compaction via previously known methods. Dynamic compaction is achieved without the use of costly hot isostatic pressing or extrusion equipment and their associated facilities. Thus, the turn-around time for dynamic compaction process powder metallurgy material can be months faster than previously known method's wait times for extruded or hot isostatic pressed powder materials. The dynamic bonding techniques disclosed herein allow bonding of similar or dissimilar powder metallurgy material at ambient temperatures with low cost tooling and fixtures. A broader design space can be achieved by use of the disclosed process including hybrid powder metallurgy material combinations and configurations. The disclosed method enables the bonding of dissimilar materials and blend ratios, e.g., ceramic/metallic powders, insitu ceramic/metallic powders, nano insitu ceramic/metallic powders that could not previously be achieved.

**[0049]** There has been provided a dynamic compaction process. While the dynamic compaction process has been described in the context of specific embodiments

thereof, other unforeseen alternatives, modifications, and variations may become apparent to those skilled in the art having read the foregoing description. Accordingly, it is intended to embrace those alternatives, modifications, and variations which fall within the broad scope of the appended claims.

## Claims

1. A dynamic compaction process comprising:
  - providing a container (22; 116) having a non-cylindrical shape;
  - filling said container (22; 116) with a first powder material (18; 110, 114);
  - sealing said container (22; 116); and
  - dynamically compacting said first powder material (18; 110, 114).
2. The process according to claim 1, wherein said first powder material (18; 110, 114) comprises a nickel alloy.
3. The process according to claim 1 or 2, further comprising:
  - removing unwanted gases by use of a vacuum on said first container (22; 116) subsequent to filling the container (22; 116).
4. The process according to any preceding claim, further comprising:
  - forming a component (28; 132) from a preform (112) of said first powder material (18; 110, 114).
5. The process according to claim 4, wherein said component (28; 132) comprises a blade having a tip portion (12), airfoil portion (16) and root portion (14) formed from said first powder material (18; 110; 114).
6. The process according to any preceding claim, further comprising:
  - forming a component precursor (10; 100) from the solid powder metallurgy material (18; 110, 114); and
  - cutting at least one blade from said component precursor (10; 100).
7. The process according to any preceding claim, further comprising:
  - dynamically compacting said first powder material (18; 110, 114) by use of a compaction mat (126).
8. The process according to claim 7, further comprising:
  - aligning said compaction mat (126) at an exterior surface (24; 128) of said container (22; 116) opposite an immovable object (129).
9. The process according to claim 7, wherein said dynamic compaction is initiated by a fuse (130) coupled to said compaction mat (126) proximate a first end (120) of said container (22; 116).
10. The process according to claim 9, wherein said dynamic compaction occurs across said container exterior surface (24; 128) from said first end (120) of said container (22; 116) to a second end (122) of said container (22; 116).
11. An aerospace component (28; 132) comprising a first alloy powder metallurgy material (18; 110, 114) bonded together with dynamic compaction.
12. The aerospace component according to claim 11, wherein said aerospace component (28; 132) is near net shape, and/or wherein said aerospace component (28; 132) is a blade.
13. A container (22; 116) for dynamic compaction of an alloy powder metallurgy material (18; 110, 114), wherein the container (22; 116) has a non-cylindrical shape and is configured to encapsulate said alloy powder metallurgy material (18; 110, 114).
14. The container of claim 13, wherein said non-cylindrical shape is selected from the group consisting of a blade shape, a vane shape and an airfoil shape.
15. The container of claim 13 or 14, wherein said container (22; 116) comprises a filling tube (26; 124) configured to receive said alloy powder metallurgy material (18; 110, 114) for insertion into a cavity (118) of said container (22; 116), wherein, optionally said filling tube (26; 124) is configured to facilitate evacuation of gases from said cavity (118) via a vacuum on said cavity (118); and/or wherein said container (26; 124) is configured to be sealed from invasive gases.



**FIG. 1**

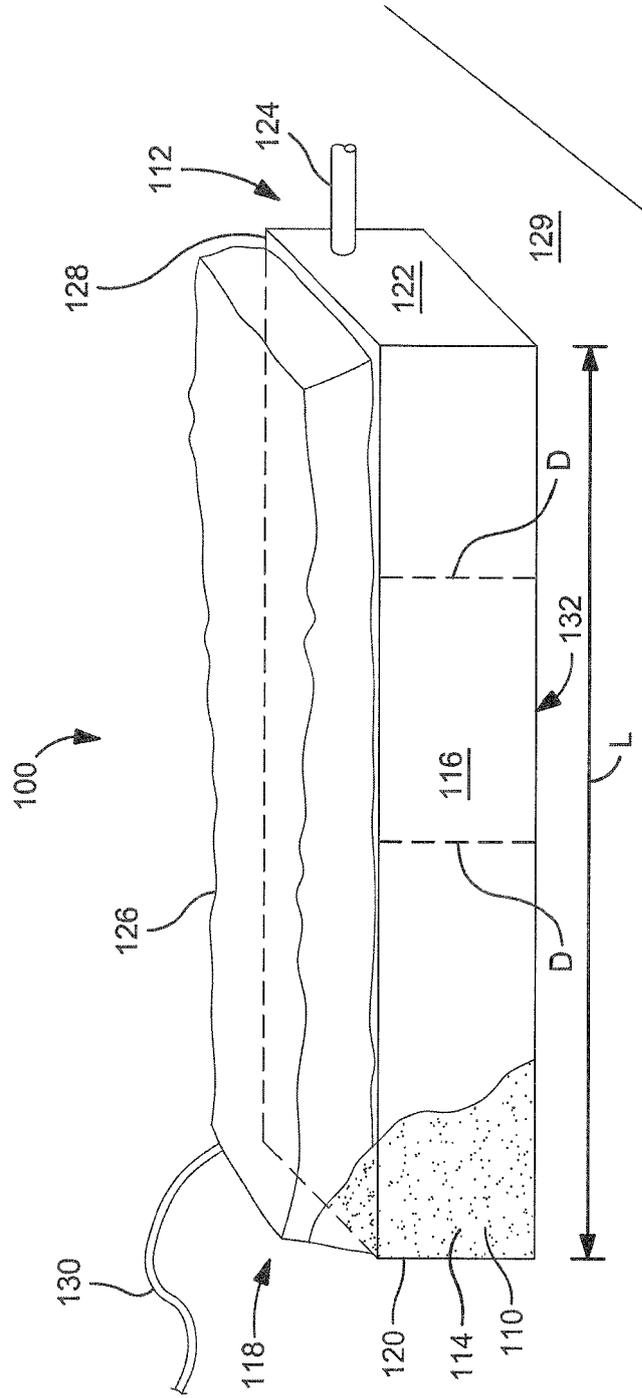
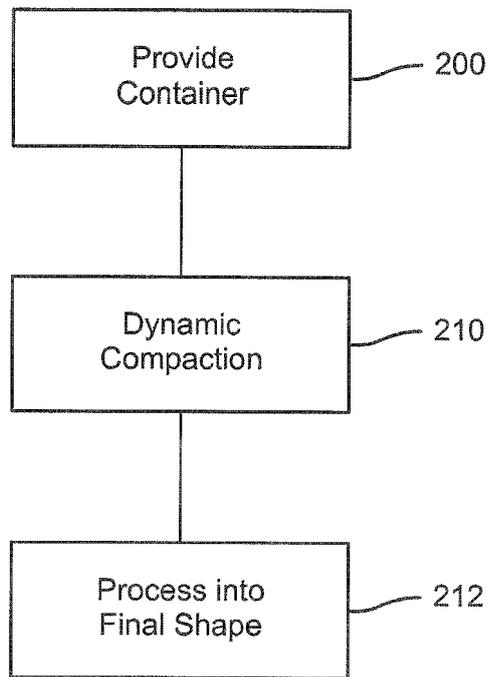


FIG. 2



**FIG. 3**



EUROPEAN SEARCH REPORT

Application Number  
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 25 April 2017	Examiner Järvi, Tommi
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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ANNEX TO THE EUROPEAN SEARCH REPORT  
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.  
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