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(54) **A method for manufacturing a MMC component**

(57) A method for manufacturing an wear resistant component comprising the steps:
- providing a capsule defining at least a portion of the final shape of the component;
- providing a powder mixture comprising tungsten carbide particles and particles of a nickel-based or a cobalt based alloy:
- filling at least a portion of said form with said powder mixture;
- subjecting said form to Hot Isostatic Pressing (HIP) at a predetermined temperature, a predetermined isostatic pressure and for a predetermined time so that the particles of the nickel-based or the chromium based alloy bond metallurgical to each other:
characterized in that the tungsten carbide particles have a size of ≥ 250 µm and that the mean size of the nickel based or chromium based alloy is ≤ 1/5 of the size of the tungsten carbide particles.

EP 2 808 107 A1

## Description

TECHNICAL FIELD

**[0001]** The present invention relates to a method for manufacturing a wear resistant component according to the preamble of claim 1. The invention also relates to a wear resistant component according to the preamble of claim 14.

BACKGROUND ART

**[0002]** Components that are subjected to wear, such as abrasion resistant components in mining applications, are typically provided with a layer of wear resistant material which consists of hard, wear resistant particles in a ductile steel matrix, a so called Metal Matrix Composite (MMC). In certain cases the entire component may be manufactured in a wear resistant material.

**[0003]** One method for manufacturing wear resistant MMC components is Plasma Transferred Arc Welding (PTAW). In PTAW, a powder mixture of hard tungsten carbide particles and ductile metal powder is fed through a nozzle into plasma, in which the powder is fused so that the solid tungsten carbide particles are suspended in molten metal powder. The fused powder is transferred onto the surface of the steel component where it solidifies.

**[0004]** However, wear resistant layers that have been applied by PTAW suffer from several drawbacks. For instance, during solidifying of wear resistant layers applied by PTAW, the alloy elements segregate in the molten metal matrix and cause inclusions of e.g. borides and carbides to grow rapidly into large blocks or elongated needle like shapes. As the inclusions grow, they connect with each other and form brittle networks in the ductile metal phase between adjacent tungsten carbide particles, hence reducing the ductility of the wear resistant layer. A further drawback with PTAW layers is that, due to differences in density between tungsten carbide and the metal alloy of the binder phase, the tungsten carbides tend to sink towards the bottom of the applied wear resistant layer. This causes a lower concentration of hard particles in the surface region of the wear resistant layer, thus reducing the hardness at the surface of the wear resistant layer.

**[0005]** Another know method of manufacturing wear resistant layer or products is by HIP (Hot Isostatic Pressing) in which a blend of hard particles, such as tungsten carbide, and ductile metallic particles are bonded metallurgically under high pressure and high temperature. The HIP process results in a component having homogenous properties and structure throughout the cross section.

**[0006]** One typical area of use for Metal Matrix Composites is in applications where the predominant wear mechanism is abrasion, i.e. in which particles slide over a surface and causes wear by scratching the surface. This is for example a common wear mechanism in impellers for transporting slurries of water and sand.

**[0007]** Attempts have been made to increase the wear resistance in MMC under abrasive conditions by increasing the fraction of hard particles in relation to the fraction of the ductile steel matrix. However, when slurries of coarse sand material, so called "gravel" is transported at high pressure it has been found that MMC materials with high fractions of hard particles does not exhibit sufficient wear resistance.

**[0008]** Hence, it is an object of the present invention to provide a method for manufacturing of Metal Matrix Composites with high resistance to wear. A further object of the present invention is to provide a component obtained by the inventive method.

SUMMARY OF THE INVENTION

**[0009]** According to a first aspect of the invention the above object is achieved by a method for manufacturing a wear resistant component comprising the steps:

- providing a capsule defining at least a portion of the final shape of the component;
- providing a powder mixture comprising tungsten carbide particles and particles of a nickel-based or a cobalt based alloy:
- filling at least a portion of said form with said powder mixture;
- subjecting said form to Hot Isostatic Pressing (HIP) at a predetermined temperature, a predetermined isostatic pressure and for a predetermined time so that the particles of the nickel-based or the cobalt based alloy bond metallurgical to each other:

**characterized in that** the tungsten carbide particles have a mean size of ≥ 250 μm and that the size of the nickel based or cobalt based alloy is ≤ 1/5 of the size of the tungsten carbide particles.

**[0010]** The invention also relates to a component which is obtained by the inventive method.

**[0011]** It is believed that the good resistance to abrasion of the MMC material obtained by the inventive method is due to a combinatory effect of the large size tungsten carbides and the carefully selected size of the ductile alloy particles which constitutes the matrix.

**[0012]** The size of the ductile alloy particles have been carefully selected with regard to the size of the tungsten carbide particles. Therefore, when the particles of tungsten carbide and matrix alloy are mixed during manufacturing of the component, the ductile alloy particles are brought to completely surround essentially each individual tungsten carbide particle. In the final component, this in turn has the effect that essentially each large tungsten carbide particle is kept firmly in place in the ductile matrix and that brittle networks of interconnected tungsten particles are avoided. Since the size of the tungsten particles in the component is large, i.e. larger than 250 μm, the load from a gravel particle which slides over, or impinges the surface of the component is essentially taken by the tungsten particles and the resulting damage on the component is small.

**[0013]** The wear resistance of the inventive MMC material in comparison to a conventional material will in the following be described with reference to figures 1a, 1b and 2a, 2b.

Figure 1a shows schematically a cross section of a MMC-material 1 according to the invention. The MMC material 1 comprises tungsten carbide particles 2 having a size of ≤ 250 μm, e.g. 350 μm that are embedded in a ductile alloy matrix 3 of e.g. nickel base or cobalt base alloy. A large gravel particle 4 (schematically indicated by the ellips) slides over the surface of the component. The large tungsten carbide particles essentially absorb the entire load from the gravel particle 4. Therefore the resulting damage on the component 1 is limited to the ductile alloy matrix 3 between the tungsten carbide particles 3 that are hit by the gravel particle 4, see figure 1b.

Figure 2a shows in comparison a cross-section of a conventional MMC material 1 having tungsten carbide particles 2 of a mean size of 60 - 180 μm in a ductile alloy matrix 3. As a gravel particle 4 slides over the surface of the conventional component 1, the relatively small tungsten carbide particles 2 fail to absorb the load from the gravel particle 40 which in turn results in that a large piece of the MMC is torn away from the component.

**[0014]** Further alternatives and embodiments of the invention as described above and hereinafter are disclosed in the dependent claims and the following detailed description.

DEFINITIONS

**[0015]** By "sand" is meant is a granular material composed of finely divided rock and mineral particles that have a general particle size up to 2 mm.

**[0016]** By "gravel" is meant unconsolidated rock fragments that have a general particle size above 2 mm typically 2 mm - 64 mm.

BRIEF DESCRIPTION OF DRAWINGS

**[0017]**

Figure 1a and 1b shows schematically an inventive MMC material when subjected by wear from a gravel particle.

Figure 2a and 2b shows schematically a conventional MMC material when subjected to wear from a gravel particle.

Figure 3 is a flow chart showing the principal steps of the inventive method.

Figure 4a to 4d are shows schematically the capsule used in the inventive method.

DETAILED DESCRIPTION OF THE INVENTION

**[0018]** The invention will in the following be described with reference to figure 3 which a flowchart over the steps of the inventive method.

**[0019]** In a first step, a capsule 10 is provided. The capsule 10, also referred to as mould or form, is shown in side view in figure 4a and defines at least a portion of the shape or contour of the final component. The capsule 10 is typically manufactured from steel sheets, such as carbon steel sheets that are welded together. The capsule may have any shape. In figure 4a, the capsule defines the outer shape of a cylinder and has a circular bottom plate 11, a circumferential outer wall 12 and a cover 13 which is sealed to the outer wall 12 by welding after filling of the form. The capsule 10 may also define a portion of the final component. In that case the capsule 10 is welded to a pre-manufactured component 14, for example a forged or cast component. The capsule 10 is thereby designed such that one of the walls of the capsule, or its bottom, is constituted by a surface of the pre-manufactured component 14, see figure 4b. This has the advantage that pre-manufactured components may be provided with a layer of wear resistant material.

**[0020]** In a second step a powder mixture is provided. According to the invention the powder mixture consists of a powder of tungsten carbide particles and a powder of a nickel based alloy or cobalt based alloy. The tungsten carbide particles may be WC or $W_2C$ or a mixture of WC and $W_2C$. The tungsten carbide particles may be of spherical or facetted shape. The mean size of the tungsten particles is at least 250 μm, i.e. ≤ 250 μm.

**[0021]** In the final component, the large tungsten carbide particles provide wear resistance by absorbing the load from gravel that impinges or slides over the surface of the component. It is believed that tungsten particle sizes of at least 250 μm provides very good resistance to abrasive wear from gravel slurries or sand slurries, even under conditions that cause the abrasive/erosive particles to wear the surface with high normal force. The wear resistance to gravel size particles increases with increasing size of the tungsten particles. However, when the size of the tungsten particles exceed 650 μm the resulting mean distance between the tungsten particles becomes very large which in turn may result in that the ductile matrix phase is eroded, so called wash-out. According to one embodiment, the mean size of the tungsten particles is 250 - 450 μm. It is believed that these sizes provides good resistance to slurries containing a predominant fraction of sand sized particles. According to a second embodiment, the mean size of the tungsten particles is 450 - 650 μm. It is believed that these sizes provides good resistance to slurries containing a predominant fraction of gravel sized particles.

**[0022]** The powder of the nickel based or cobalt based alloy constitutes the ductile phase in the final consolidated component. By "cobalt-based" or "nickel-based" is meant that the main constituent in the alloy is nickel respectively cobalt.

**[0023]** Nickel based alloys are generally strong and ductile and therefore very suitable as matrix material in abrasive resistant applications. A further advantage with nickel based alloys is that carbon has very low solubility in nickel, which constitutes the main element of the alloy. Low solubility of carbon is an important characteristic in the matrix material in order to avoid dissolving of the tungsten particles. Nickel is further inexpensive in comparison to cobalt, another conventional matrix material.

**[0024]** Cobalt based alloys are known to provide good wettability towards the tungsten carbides which improves bonding. In addition thereto, in applications where high angle impingement erosion is a strongly contributing wear mechanism, a cobalt based matrix provides better wear resistance compared to other types of matrix material.

**[0025]** The nickel based or cobalt based alloy should preferably contain chromium in an amount of 3 - 35wt% or 3-20 wt%, preferably 12-20 wt%.

**[0026]** Chromium forms together with carbon and iron, small metal rich carbides, for example $M_{23}C_6$ and $M_7C_3$ that are precipitated in the ductile nickel based alloy matrix. The precipitated carbides strengthen the matrix by blocking dislocations from propagating. Since the precipitated particles also are hard, they also increase the wear resistance of the matrix. However, since chromium is a strong carbide former, high amount of chromium could lead to decomposition of the large tungsten carbide particles.

**[0027]** The powder of the nickel based alloy may have the following composition in weight % (wt%): C: 0 - 1.0; Cr: 3 - 20; Si: 2.5 - 4.5; B: 1.25 - 3.0; Fe: 1.0 - 4.5; the balance Ni and unavoidable impurities.

**[0028]** The powder of cobalt based alloy may have the following composition in weight % (wt%): %): C: 0 - 3.0; Cr: 3 - 35; W: 0-20; Mo: 0-15; Si: 0.3 - 1.5; Fe: 1.0 - 10; the balance Co and unavoidable impurities.

**[0029]** The nickel based or cobalt based alloy particles have a substantially spherical shape, alternatively a deformed spherical shape.

**[0030]** The size of the nickel based or cobalt based alloy particles is ≤1/ 5 of the size of the tungsten carbide particles in the powder mixture. For example, the size of the alloy particles is 50 μm if the mean size of the tungsten carbide particles is 250 μm and the size of the alloy particles is 1/5 of the size of the tungsten carbide particles. When very large alloy particles are used, the tungsten particles may not be sufficiently embedded in alloy powder and thus form brittle networks which reduce wear resistance and toughness of the material. Therefore the size of the alloy particles is set to maximum 1/5 of the size of the tungsten particles. The minimum size of the alloy particles is preferably limited to 10 μm since powder of smaller size is difficult to handle. For example the size of the nickel based or cobalt based alloy particles is 1/10 - 1/5 or 1/8 - 1/6 of the size of the tungsten carbide particles in the powder mixture.

**[0031]** According to a preferred embodiment the size of the tungsten carbide particles is 250 -450 μm and the size of the alloy particles is 1/20 - 1/10 of the size of the tungsten carbide particles. A material manufacture of a powder of this size distribution is believed to have very good resistance to wear from slurries containing predominantly sand.

**[0032]** According to a preferred embodiment the size of the tungsten carbide particles is 450 -650 μm and the size of the alloy particles is 1/30 - 1/20 of the size of the tungsten carbide particles. A material manufacture of a powder of this size distribution is believed to have very good resistance to wear from slurries containing predominantly gravel.

**[0033]** Without being bound by any theory, it is believed that the specific relationship between the particle sizes of the nickel or cobalt based alloy and the tungsten carbide particles ensures that the alloy powder completely surrounds the tungsten particles. Thereby it is ensured that the tungsten particles are firmly integrated in the matrix of the component. It is further avoided that brittle networks of interconnected tungsten carbide particles are formed. In practice, such network may have a negative effect on toughness and the wear resistance since the interconnected tungsten carbide particles easily could serve as paths where cracks easily propagate and thereby lead to failure of the component. As a result of crack networks, the carbides could then more easily be torned away or knocked out from the surface of the component by gravel

**[0034]** The size of the tungsten carbide particles and the size of the nickel based and cobalt based alloy particles may be determined with laser diffraction, i.e. analysis of the "halo" of diffracted light produced when a laser beam passes through a dispersion of particles in air or in liquid. The size of the nickel based or cobalt based alloy particles is measured as "d90" which means that 90% of the particles have a size which is smaller than a specific value. The size of the tungsten carbide particles is determined as the mean size of a volume of particles.

**[0035]** The powder of tungsten carbide particles is mixed with the powder of nickel or cobalt based alloy particles in a ratio of 30 -70 vol% of tungsten carbide powder and the remainder nickel based alloy powder.

**[0036]** The exact volume ratio between the tungsten carbide powder and the matrix forming alloy powder in the inventive powder mixture is determined by the wear condition in the application that the consolidated component is intended for. However, with regard to the tungsten carbide powder, the lowest acceptable amount is 30 vol% in order to achieve a significant resistance to abrasion. The amount of tungsten carbide powder should not exceed 70 vol% since the HIP:ed component then may become too brittle. It is further difficult to blend or mix amounts of tungsten carbide powder exceeding 70 vol% with the alloy particles forming the matrix to a degree where essentially all the tungsten carbide particles are completely embedded in the alloy powder.

**[0037]** The volume ratio may for example be 40 vol% tungsten carbide powder and 60 vol% alloy powder, or 50 vol% tungsten carbide powder and 50 vol% of alloy powder, or 45 vol% tungsten carbide powder and 55 vol% of alloy powder.

**[0038]** In a third, step the tungsten carbide powder and the alloy powder forming the matrix are blended into a powder mixture. Blending is preferably performed in V-type mixer. The blending step ensures that the tungsten carbide particles are distributed uniformly in the volume of inventive powder mixture and that essentially all tungsten carbide particles are individually embedded in alloy powder.

**[0039]** In a fourth step, se figure 4c, the powder mixture 16 is poured into the capsule 10 that defines the shape of the component. The capsule is thereafter sealed, for example by welding the cover 13 onto the circumferential wall 12. Prior to sealing the capsule 10, a vacuum may be applied to the powder mixture, for example by the use of a vacuum pump. The vacuum removes the air from the powder mixture. It is important to remove the air from the powder mixture since air contains argon, which has a negative effect on ductility of the resulting material.

**[0040]** In a fifth step, see figure 4d, the filled capsule 10 is subjected to Hot Isostatic Pressing (HIP) at a predetermined temperature, a predetermined isostatic pressure and for a predetermined time so that the particles of the alloy powder forming the matrix bond metallurgical to each other. The powder containing capsule 10 is thereby placed in a heatable pressure chamber 17, normally referred to as a Hot Isostatic Pressing-chamber (HIP-chamber).

**[0041]** The heating chamber is pressurized with gas, e.g. argon gas, to an isostatic pressure in excess of 500 bar. Typically the isostatic pressure is 900 - 1200 bar. The chamber is heated to a temperature which is below the melting point of nickel or cobalt based alloy powder. The closer the temperature is to the melting point, the higher is the risk for the formation of melted phase and unwanted streaks of brittle carbide- and boride networks. Therefore, the temperature should be as low as possible in the furnace during HIP:ing. However, at low temperatures the diffusion process slows down and the material will contain residual porosity and the metallurgical bond between the particles becomes weak. Therefore, the temperature is 900 - 1150°C, preferably 1000 - 1150°C. The form is held in the heating chamber at the predetermined pressure and the predetermined temperature for a predetermined time period. The diffusion processes that take place between the powder particles during HIPP:ing are time dependent so long times are preferred. Preferable, the form should be HIP:ed for a time period of 0.5 - 3 hours, preferably 1 - 2 hours, most preferred 1 hour.

**[0042]** During HIP:ing the particles of the nickel based alloy powder deform plastically and bond metallurgically through various diffusion processes to each other and the tungsten particles so that a dense, coherent article of diffusion bonded nickel based alloy particles is formed. In metallurgic bonding, metallic surfaces bond together flawlessly with an interface that is free of defects such as oxides, inclusions or other contaminants.

**[0043]** After HIP:ing the capsule is stripped from the consolidated component. Alternatively, the form may be left on the component.

**[0044]** It is possible to take a sample of the HIP:ed component, etching the surface of the sample and determine in SEM (Scanning Electron Microscope) that the particles are diffusion bonded to each other.

## Claims

1. A method for manufacturing an wear resistant component comprising the steps:

   - providing a capsule defining at least a portion of the final shape of the component;
   - providing a powder mixture comprising tungsten carbide particles and particles of a nickel-based or a cobalt based alloy:
   - filling at least a portion of said form with said powder mixture;
   - subjecting said form to Hot Isostatic Pressing (HIP) at a predetermined temperature, a predetermined isostatic pressure and for a predetermined time so that the particles of the nickel-based or the cobalt based alloy bond metallurgical to each other:

   **characterized in that** the tungsten carbide particles have a mean size of $\geq 250$ $\mu$m and that the size of the nickel based or cobalt based alloy is $\leq$ 1/5 of the size of the tungsten carbide particles.

2. The method according to claim 1, wherein the mean size of the tungsten carbide particles is 250 - 450 $\mu$m.

3. The method according to claim 1 or 2, wherein the mean size of the tungsten carbide particles is 450 - 650 $\mu$m.

4. The method according to any of the preceding claims, wherein the size of the particles of the nickel-based or the cobalt based alloy is 1/10 - 1/5 of the mean size of the tungsten carbide particles.

5. The method according to any of the preceding claims, wherein the size of the particles of the nickel-based or the cobalt based alloy is 1/8 - 1/6 of the

mean size of the tungsten carbide particles.

**6.** The method according to any of the preceding claims, wherein the size of the nickel-based or the cobalt based alloy is ≥ 1/30 of the mean size of the tungsten carbide particles.

**7.** The method according to any of the preceding claims, wherein the mean size of the tungsten carbide particles is 250 - 450 μm and the size of the nickel based or cobalt based alloy is 1/10 - 1/20 of the size of the tungsten carbide particles.

**8.** The method according to any of the preceding claims, wherein the mean size of the tungsten carbide particles is 450 - 650 μm and the size of the nickel based or cobalt based alloy is 1/20 - 1/30 of the size of the tungsten carbide particles.

**9.** The method according to any of claims 1-8, wherein the nickel based or the cobalt based alloy comprises chromium in an amount of 3 - 35wt%, preferably 3-20 wt%, more preferred 12-20 wt%.

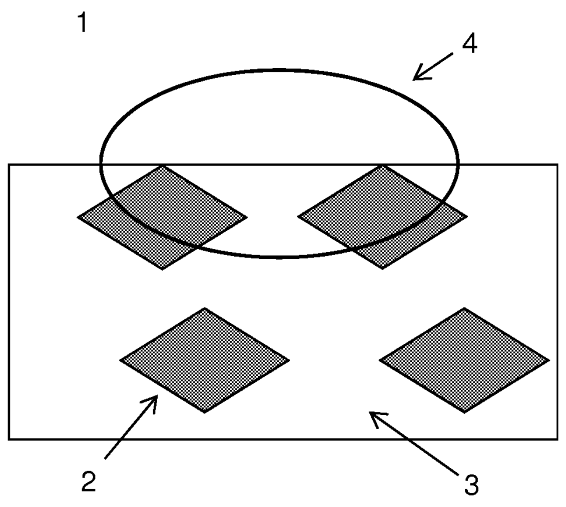
**10.** The method according to any of claims 1-8, wherein the nickel-based or the cobalt based alloy comprises ≥ 12 wt% of chromium.

**11.** The method according to any of claims 1 -8 wherein the cobalt based alloy has the following composition (in wt%): C: 0 - 3.0; Cr: 3 - 35; W: 0-20; Mo: 0-15; Si: 0.3 - 1.5; Fe: 1.0 - 10; the balance Co and unavoidable impurities.

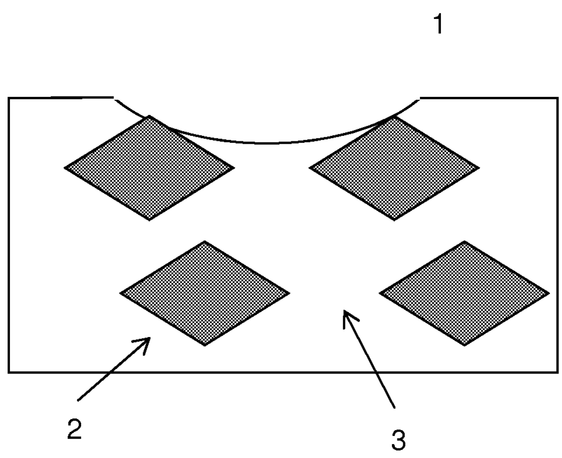
**12.** The method according to any of claims 1 -8, wherein the nickel based alloy has the following composition (in wt%): C: 0 - 1.0; Cr: 3 - 20; Si: 2.5 - 4.5; B: 1.25 - 3.0; Fe: 1.0 - 4.5; the balance Ni and unavoidable impurities.

**13.** The method according to any of the preceding claims, wherein the powder mixture comprises 30-70 vol% of tungsten carbide particles and remainder particles of the nickel based or the cobalt based alloy.

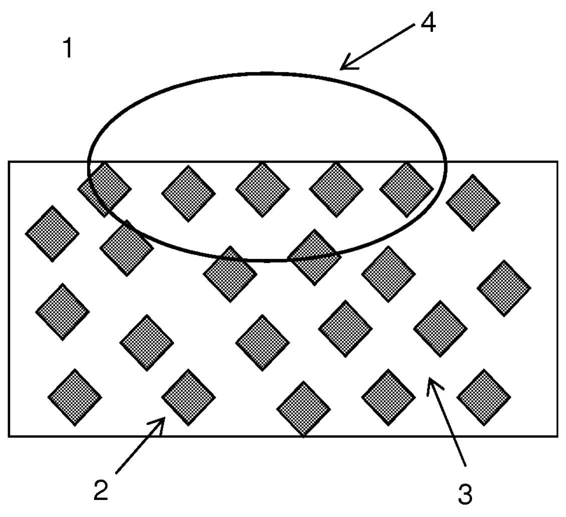
**14.** A wear resistant component obtained by the method according to any one of claims 1-12.



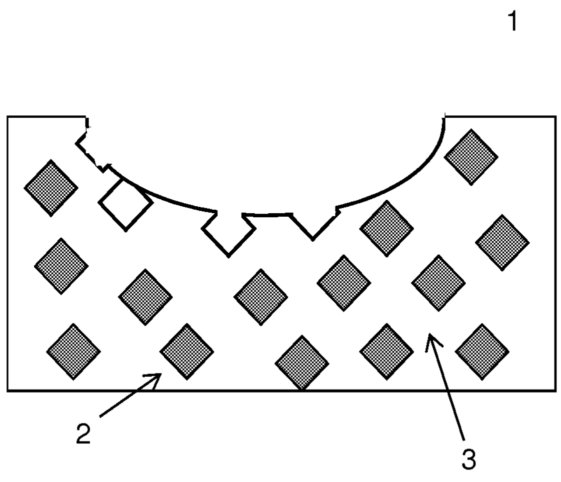

**Figur 1a**




**Figur 1b**




**Figur 2a**




**Figur 2b**

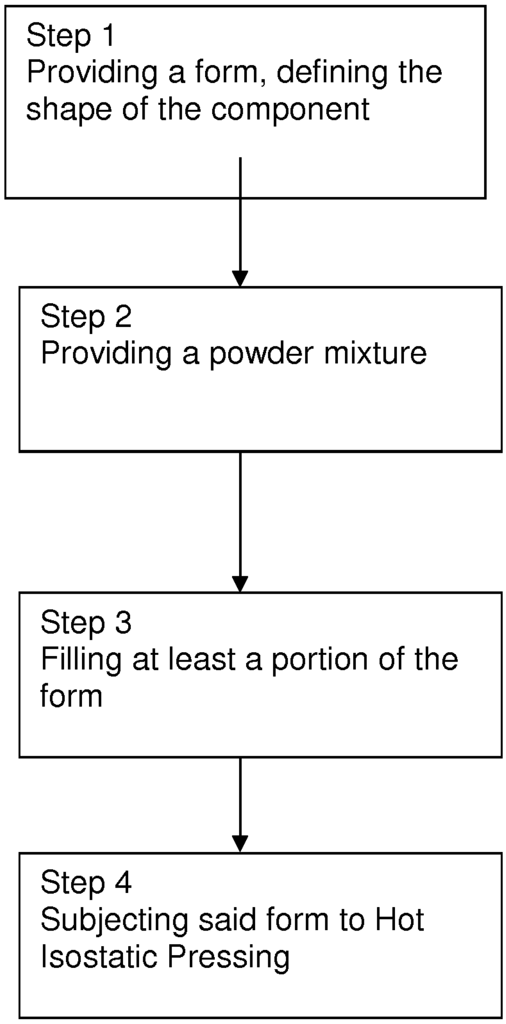

Step 1
Providing a form, defining the shape of the component
Step 2
Providing a powder mixture
Step 3
Filling at least a portion of the form
Step 4
Subjecting said form to Hot Isostatic Pressing

**Figure 3**

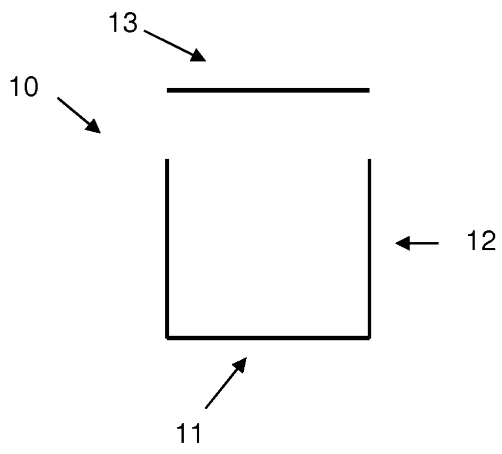



Figure 4a

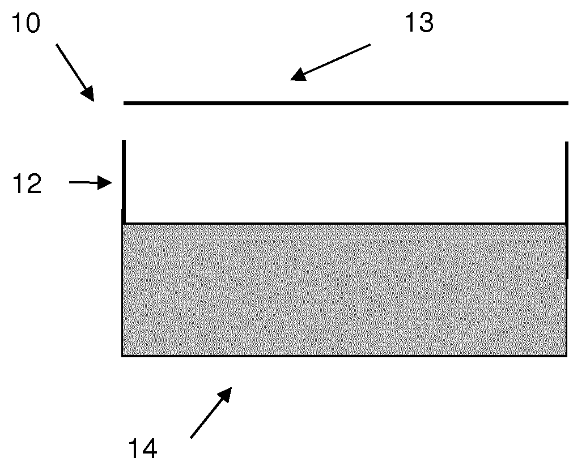



Figure 4b

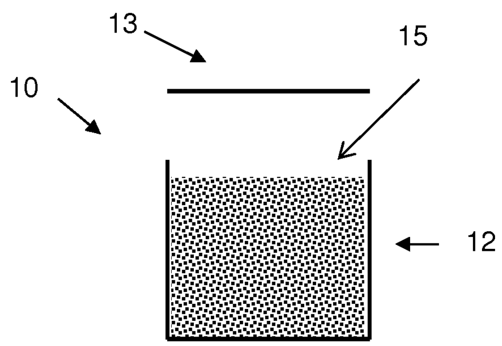



Figure 4b

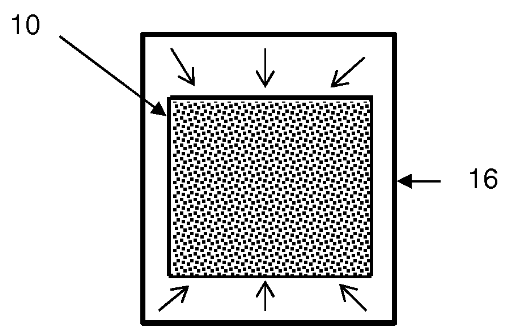



Figure 4c

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# EUROPEAN SEARCH REPORT

Application Number
EP 13 16 9963

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
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| A | US 2011/031028 A1 (SRESHTA HAROLD [US] ET AL) 10 February 2011 (2011-02-10)<br>* paragraphs [0002], [0008] - [0014], [0016], [0017], [0022] - [0035], [0043] - [0047] *<br>* table 2 *<br>* figures 1-4 *<br>----- | 1-14 | TECHNICAL FIELDS SEARCHED (IPC) |
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The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| The Hague | 18 October 2013 | Stocker, Christian |

CATEGORY OF CITED DOCUMENTS

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## ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 13 16 9963

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