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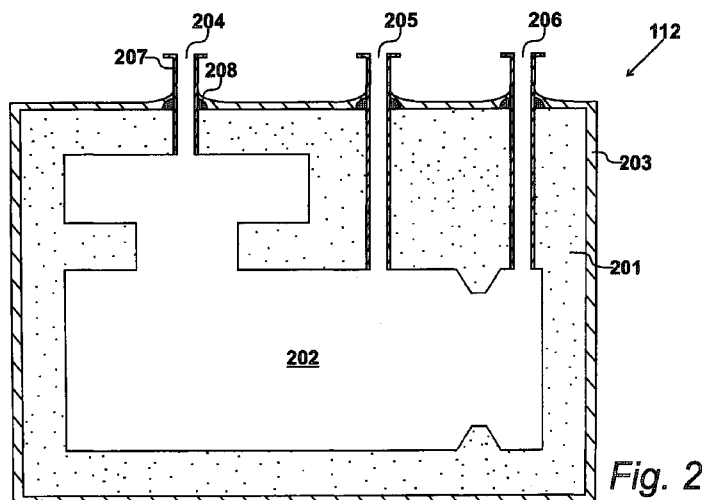


Fig. 2

(57) Abstract: A mould for use in a Hot Isostatic Press is constructed. A three-dimensional pattern is obtained and a ceramic shell is formed around it. The shell is covered in a metal layer.



A Mould for use in a Hot Isostatic Press

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from United Kingdom Patent Application No. 14 15 190.6, filed August 27, 2014, the entire disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a mould for forming a component in a Hot Isostatic Press and a method of constructing a mould for forming a component in a Hot Isostatic Press.

2. Description of the Related Art

Hot Isostatic Pressing (HIP) is a method of producing a high quality metal component such as may be used in many applications, for example aerospace. HIP is a method of heat treatment that uses high temperatures and pressures to fuse particles of material, resulting in a component with improved structural properties over forged or cast objects.

The HIP process subjects a material, either in solid or powder form, to both elevated temperature and gas isostatic pressure in a high pressure containment vessel. The material may for example be metal powder, and it may also be a solid component. For example, HIP can be used to densify existing metal components with internal voids, or to join two components together. Typically an inert gas such as argon or helium is used to form an inert pressurising atmosphere within a chamber. Under the increased temperature and pressure conditions, the particles of metal powder are agglomerated within the mould and diffusion bonded, resulting in a component that is nearly fully dense and homogenous, with a uniform microstructure in all three dimensions. The component is near net, meaning that very little further processing is required to achieve the final result.

A problem with the HIP process when forming a component in a mould is that the mould must be impermeable to the inert pressurising atmosphere and able to withstand the high temperatures used. Conventionally moulds used in the HIP process are constructed of thick sections of mild steel sheet welded together to create a can in the shape of the component. However, if the component to be produced has a complex geometry it can be very time-consuming or impossible to produce a can in this way. In addition the metal of the can may bond to the component during the HIP process, meaning that a component produced in this way will typically require further machining or chemical treatment to remove surface contamination and to refine the shape of the component.

BRIEF SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided a method of constructing a mould for use in a Hot Isostatic Press, comprising the steps of obtaining a three-dimensional pattern, forming a ceramic shell around said three-dimensional pattern, removing said pattern from inside said ceramic shell, such that a cavity is left within said ceramic shell, and covering said ceramic shell in a metal layer.

According to a second aspect of the present invention, there is provided a method of forming a component in a Hot Isostatic Press, comprising the steps of obtaining feed material, constructing a mould by obtaining a three-dimensional pattern, forming a ceramic shell around said three-dimensional pattern, removing said pattern from inside said ceramic shell, such that a cavity is left within said ceramic shell, and covering said ceramic shell in a metal layer, wherein an aperture is defined through said metal layer and said ceramic shell, filling the cavity in said mould with said feed material via said aperture, sealing the aperture defined by said metal layer, such that the mould is impermeable, placing said mould inside a Hot Isostatic Press and subjecting said mould to high temperature and isostatic gas pressure, removing said mould from the Hot Isostatic Press, and removing the finished component from said mould.

According to a third aspect of the invention, there is provided a mould for forming a component in a Hot Isostatic Press, comprising a ceramic shell defining a cavity, and a metal layer covering said ceramic shell.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Figure 1 shows a Hot Isostatic Press in which a mould as herein described may be used;

 Figure 2 shows the mould of Figure 1 in cross sectional view;

 Figure 3 shows procedures undertaken to construct a component using the HIP of Figure 1;

10 Figure 4 illustrates the construction of the mould shown in Figure 2;

 Figure 5 details steps carried out in Figure 3 to create a mould;

 Figure 6 details steps carried out in Figure 3 to fill and seal a mould;

 Figure 7 details steps carried out in Figure 4 to carry out the HIP process on a sealed mould; and

15 Figure 8 shows a component formed according to the steps of Figure 3.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

Figure 1

20 A Hot Isostatic Press (HIP) **101** is shown in schematic form in Figure 1. HIP **101** comprises a steel pressure vessel **102**, equipped with a compressor pump **103** for adjusting the pressure inside vessel **102**, and a heating system **104** for adjusting the temperature inside vessel **102**. Heating system **104** comprises a high current power source **105** and a resistive coil **106**. An electronic controller **107** receives signals from a temperature sensor **108** and a pressure sensor **109** installed inside pressure vessel **102** and operates the heating system and the compressor pump so as to adjust the temperature and pressure inside the vessel according to pre-programmed parameters. Compressor pump **103** receives a feed of argon from storage

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tank 110 so as to fill the pressure vessel with the inert gas until a desired temperature and/or pressure has been achieved. Within vessel 102 is an insulating layer 111 to protect the vessel from the high temperatures used and to ensure even distribution of the heat.

5 A mould, such as mould 112, internally defining the shape of a component to be formed and filled with a feed material, is placed on a support 113 inside pressure vessel 102. The temperature inside the vessel is increased to a predetermined temperature using heating system 104 and the pressure is increased using compressor 103 which pumps gas from storage
10 tank 110 into vessel 102 until a predetermined pressure is reached. Pressure and heat is applied to the mould isostatically, ie from all directions as indicated by the arrows, causing the mould 111 to plastically deform. After the required duration of time under increased temperature and pressure has elapsed, the temperature and pressure within the vessel 102 is adjusted to
15 atmospheric values so that the mould may be removed. The component formed within the mould is then extracted from the mould, and further processed if required.

HIP 101 is of a suitable size for the size of the components to be processed within and the temperature and pressure to be used, typically
20 anything from a metre tall to several metres tall. The materials used to construct the vessel and the insulating layer are appropriate to the temperature that the HIP will be run at. In this example vessel 102 is constructed from steel, but materials such as molybdenum, carbon graphite, tungsten, iron-chromium and so on can be used. In this example insulating
25 layer 111 is constructed from ceramic fibres and molybdenum sheets, but other suitable materials could be used.

The gas used in HIP 101 is argon, but another inert gas, such as helium, or a gas mixture could be used.

Figure 2

30 Mould 112 is shown in cross sectional view in Figure 2. Mould 112 is

an example of a mould formed using the method described herein.

As described previously, conventional moulds for forming a component using a HIP process are constructed by welding sheets of metal to the approximate shape of the component to be formed. After the HIP process the component must then be machined to the exact shape required. In addition, weld seams cause the mould to deform in a non-uniform way, meaning that the welding must be undertaken in such a way that the seams are optimally positioned. All of this makes complex parts very difficult or impossible to produce using the HIP process. Additionally, since each mould can be used only once, the length of time taken to create each mould is critical when a run of identical objects is to be produced, meaning that it can be too expensive to create complex components using the HIP process.

Thus there is herein described an alternative mould constructed from ceramic. A ceramic shell mould is relatively inexpensive, quick and easy to produce and can conform to complex component shapes and narrow component sections. However, a ceramic shell is porous to air and permeable to pressurised gasses and therefore is not suitable for use in the HIP process where the mould is subjected to elevated gas pressures. Therefore a thin metal layer is applied about the ceramic shell to form an impermeable 'skin' to prevent gas entering the mould.

Mould 112, shown before feed material is added, is suitable for forming a component under elevated temperatures and pressures by a HIP process. Mould 112 for forming a component comprises a shell 201 formed from a ceramics substance which defines a cavity 202 corresponding to the shape of a component to be formed, and a layer 203 of a metallic substance, forming an impermeable outer layer about ceramic shell 201. Mould 112 further comprises a plurality of inlet ducts 204, 205 and 206. Duct 204 comprises a metallic tube 207 to facilitate the feeding of a feed material into the cavity 203. Metallic tube 207 is comprised of a mild steel material and is embedded in the ceramic shell 201, defining an aperture 207 through which a feed material may be inserted. A small ring of cement 208 holds metal tube

207 in place.

Ceramic shell **201** is sufficiently strong to support the component to be formed during the HIP process; however, ceramic shell **201** is relatively porous to gasses and so metal layer **203** is applied about the exterior of the ceramic shell to form an impermeable layer. The metal layer **203** is in this embodiment made of mild steel, but may also be made of a pure metal such as iron, or another alloy such aluminium. After the outer metal layer **203** has been applied, it is welded to the metal tube **207**. Thus ceramic shell **201** is fully surrounded by metal, with only the inlet ducts being left open.

Inlet ducts **205** and **206** are constructed similarly to inlet duct **207**. For a simple shape only one inlet duct is required, but in order to make sure that the cavity of a complex shape is filled with feed material without leaving gaps, more than one inlet duct may be required as illustrated in Figure 2.

HIP processing is effective in powder metallurgy techniques where a component is formed from a powdered metal. Powder metallurgy has a relatively higher yield than investment casting techniques and using the HIP process can produce near net shape components requiring relatively little post processing. In an embodiment therefore, the mould **201** is configured for forming a metal component from a powdered feed material.

Therefore there is herein described a mould for forming a component in a Hot Isostatic Press, comprising a ceramic shell **201** defining a cavity **202**, and a metal layer **203** covering the ceramic shell.

In the specific embodiment illustrated, the ceramic shell **201** forms an inner layer to the mould that does not have a uniform thickness around the cavity **203**, due to the irregular shape of the cavity. However, in other embodiments, especially with less complex shapes, the thickness may be uniform. Thus the thickness of the ceramic layer will vary according to the nature of the component being produced but will typically be between 1 millimetre and 20 millimetres in thickness, either uniformly or varying across the shell. The ceramic shell **201** is a structurally integral part of the mould and so the ceramic layer must be sufficiently thick to resist cracking during

handling and subsequently heating during the HIP process.

The metal layer **203** on the other hand functions primarily as a membrane to the ceramic shell to prevent pressurised gas passing through the ceramic shell. Metal layer **203** need only be thick enough to remain intact under pressure and is not necessarily required to resist any stresses exerted on the mould during processing, and it may therefore be relatively thinner than a conventional metallic HIP can. The metallic substance is relatively more expensive than the ceramics substance and therefore the metal layer **203** should be as thin as is feasibly possible. In this embodiment it is uniformly 0.50 millimetres in thickness. It is envisaged that metal layer **203** may in other embodiments be between 0.10 millimetres and 10.0 millimetres thick.

In this embodiment the metal layer adheres to the relatively porous ceramic shell by diffusing into the outer surface of the ceramic shell. The bond between the metallic outer layer and the ceramic shell may be further improved by using a ceramic substance comprising relatively coarse ceramic particles, or by applying a final layer of coarse ceramic slurry to the ceramic shell. However, in other embodiments the metal layer need not be bonded to the ceramic layer, as long as the layers are held together immoveably, for example by the metal tubes.

In a further embodiment, a mould may be constructed about a component cast using a conventional investment casting process, to allow the cast component to be post-treated using the HIP process to increase its density and reduce its micro-porosity. In this case the ceramic shell would be formed around the component, with no inlet duct, and the metal layer would entirely encase the ceramic shell. Dissimilar pre-formed components may be encased within such a mould and subjected to a HIP process to fuse the two or more components together.

Figure 3

An overview of procedures undertaken to construct a mould for

forming a component is shown in Figure 3.

At step **301** the mould is created, as will be described further with respect to Figures 4 and 5. At step **302** the mould is filled and sealed, as will be described further with respect to Figure 6 (this step may be skipped if the mould has been formed around a pre-formed component as described with reference to Figure 3). At step **303** the HIP process is carried out, as will be described further with respect to Figure 7, and at step **304** further processing of the component is carried out.

Figure 4

An illustration of the creation of a mould, such as mould **112**, is shown in Figure 4. The illustrations are in cross-section.

To create mould **112**, first a sacrificial positive pattern **401** of the component to be formed is created. This pattern will be slightly larger than the desired component, due to the shrinking of the mould in the HIP process. The pattern **401** may be created from scratch. For example, it may be formed from tooled polystyrene, or printed using a stereo lithography procedure. Alternatively, it may be formed by introducing a substance such as wax into a permanent mould **402**. This mould may be time-consuming to create but can be used to create many patterns **401**, and therefore many HIP moulds. This is in contrast to a HIP mould made of metal, which is used only once.

A ceramics substance is then arranged around pattern **401** to create ceramic shell **201**. At this stage metal tubes are also encased in the ceramics shell and fixed using cement, as described with reference to Figure 2.

Pattern **401** is then removed from ceramic shell **201**, for example by melting or chemical treatment, leaving cavity **203**.

Finally, metal layer **203** is applied to the outside of ceramic shell **201** and welded to the metal tubes. The mould **112** is complete.

Figure 5

Step 301, illustrated in Figure 4, is detailed in Figure 5.

At step 501, a three-dimensional pattern 401 of the component to be formed is created, to define the geometry of the component to be formed. The positive pattern may be created by modelling a rapid prototyping material, by casting a wax or by machining a soft plastics material etc. However, it should be appreciated that the material used to create the positive pattern must be of a type such that it is possible to remove the material from the ceramic shell without damaging the mould. Thus, a sacrificial positive pattern defining the shape of the component to be formed is created at step 501. The sacrificial pattern is slightly larger than the eventual required component.

At step 502 a ceramics substance is arranged to create ceramic shell 201. In this embodiment, the ceramics substance is applied around the exterior of the pattern 401. Thus, the ceramics substance is applied as a wet slurry consisting of hard ceramic particles suspended within a liquid binder. The wet slurry may be applied to the exterior of the positive pattern as a plurality of layers. A first coat of a primary refractory slurry may be applied that is inert to the charge material being used, followed by alternating layers of ceramic slurry and a dry stucco. This process may be repeated until the layer of ceramic substance is sufficiently thick and strong to resist cracking during handling. The layers of ceramic slurry are allowed to dry and harden to form a ceramic shell. In a further embodiment, the ceramics substance may require firing to cause it to harden prior to the application of the layer of a metallic substance.

At step 503, the ceramic shell has hardened and has adopted the shape of the component to be formed and the material forming sacrificial pattern 401 is removed. Depending on the type of material used the pattern may be removed by the application of heat and or solvent. Thus the sacrificial pattern material is evacuated from the ceramic shell through the inlet duct leaving a cavity within the ceramic shell defining the exterior shape of the

component to be formed. However, the ceramic shell is porous to gasses.

At step **504** a metallic substance is applied to form an impermeable outer layer about the ceramic shell. The metallic coating may be applied in a number of ways and may comprise any one, or a combination of suitable metals, such as mild steel, stainless steel, aluminium, titanium etc. The metal must be able to withstand the temperature of the HIP, and is therefore chosen accordingly. The outer surface of the ceramic shell of mould **112** is relatively regular and so the metallic outer layer could be applied in a substantially conventional hard-facing manner by welding sheets of metal about the ceramic shell.

However, in other examples, the outer surface of the ceramic shell may follow the shape of the component to be produced closely and so may have a relatively complex shape. In this case, the metallic outer layer could be applied by immersing the ceramic shell in a reservoir of molten metal, thereby allowing a thin coating of metal to form on the relatively cooler ceramic shell. Alternatively, the metallic substance could be deposited as a layer of heated metal particles onto the exterior of the ceramics substance using a thermal spraying technique, such as by plasma spraying. A further possible method comprises wrapping metal foil around the ceramic shell and applying heat to it, such as a flame, plasma or an electron beam, at a temperature that melts the foil into the shape of the ceramic shell but does not cause the metal to drip. Other methods include sputtercoating and vapour deposition. Any method of applying a metal layer to a ceramic shell may be used, whether or not the metal is bonded to the ceramic during the process.

Therefore a number of methods exist for applying the metallic layer and a method suitable for the type of metal will be selected. In the embodiment described with reference to Figure 2, one or more metallic tubes are embedded in the ceramic shell forming an inlet duct through which the mould may be charged, and thus when the metallic layer is applied it may be welded to the metallic tube if necessary. Alternatively the method of applying

the metal layer may have already bonded the metal to the metal tubes.

Figure 6

Step 302, to fill and seal the mould, is detailed in Figure 6.

At step 601 a mould such as mould 112 is filled with a feed material.
5 In this embodiment the component is to be produced from a powdered metal material consisting of small particles of metal powder. Thus, the metal powder is inserted via an inlet duct into the internal cavity defined by the mould so as to fill the cavity. The HIP process is relatively flexible and metal components may be produced from a number of different metals and metal
10 alloys such as steel, titanium and aluminium.

At step 602 a vacuum pump is attached to the inlet duct of the mould and any air remaining inside the mould is removed. It is important that as much air as possible is removed from the mould to prevent the mould fracturing when heated, and to ensure that the formed component is fully
15 dense.

Following the removal of air from the mould, at step 603 the inlet ducts are crimped or capped to seal the mould and prevent air entering the mould. Thus the ceramic shell is entirely contained within the sealed metal outer layer.

20 Alternatively, if the ceramic shell has been formed around one or more pre-formed components, as described with reference to Figure 2, then the mould is already filled and sealed and step 302 need not be carried out.

Figure 7

Figure 7 details step 303, at which the HIP process is carried out.

25 At step 701 the filled mould is placed in a HIP pressure vessel as described previously with reference to Figure 1. The pressure vessel is then closed and sealed and the HIP process is initiated.

At step 702 the interior of the vessel is heated to a predetermined temperature causing the pressure inside the vessel to increase. In addition, a

compressor system is used to further increase the pressure and to fill the vessel with an inert gas such as argon. The gas pressure inside the vessel will typically be raised to between 100 and 200 megapascals and the temperature increased in excess of 1000°C causing the particles of metal powder to fuse together. In this embodiment, the temperature is raised to below the liquidus point of the metal powder so as to sinter the particles resulting in solid state diffusion of the particles. Under the elevated pressures the mould plastically deforms thereby compressing the powdered feed material within, resulting in an extremely dense component with few gas voids. The elevated temperatures and pressures of step 702 are maintained for the optimum period of time to ensure that the component is fully densified. In the HIP shown in Figure 1, the temperature inside the vessel is increased using a resistance heating element. Alternatively, an induction heating system may be used to heat the mould or the charge directly, or a susceptor element may be interposed between the mould and the induction heating system to radiate heat towards the mould.

At step 703 the HIP process is finished and the pressure and temperature inside the vessel are allowed to return to atmospheric values. The vessel is then opened and the mould extracted.

At step 704 the mould is removed from around the component. In this embodiment the mould is a single piece construction and so must be destroyed to remove the component. A mould as herein described is easier to remove from around the component than is a conventional steel HIP can. The metal outer layer 203 of the mould 112 is separated from the component by the ceramic shell 201. Thus the metal outer layer is easily cut away without risking damage to the component. The ceramic shell is then removed either mechanically or by chemically dissolving the ceramic material using a solvent.

Figure 8

Figure 8 illustrates a component produced by HIP 101 using mould

112, before the further processing of step **304** has been carried out. As can be seen the component **801** is in the shape of the cavity **202** defined by ceramic shell **201**, but is a little smaller due to the plastic deformation of mould **112** during the HIP process. Component **801** includes stems **801**, **802** and **803**, where the metal powder has taken on the shape of the metal tubes. These are machined away in processing. Additional further processing may be required to refine component **801**'s shape or mechanical properties if required.

Thus a component **801** is formed, by obtaining feed material, constructing a mould **112** by forming a ceramic shell **201** around a three-dimensional pattern **401** and removing the pattern to leave a cavity **202**, covering the ceramic shell in a metal layer **203**, leaving an aperture **204** through the mould, filling the cavity with the feed material via the aperture and sealing the metal of the aperture to make the mould impermeable, placing the mould inside a Hot Isostatic Press **101** and subjecting it to high temperature and isostatic gas pressure, removing the mould from the HIP, and removing the finished component from the mould.

A benefit of a mould described herein arises in that conventional HIP cans, being subjected to the elevated temperatures and pressures of the HIP process, will tend to bond to the surface of the component being formed. Thus, the finished component may have surface contamination and will require chemical milling to remove the diffusion layer. For example when casting a titanium component using a conventional steel HIP can, the surface of the titanium component will tend to become contaminated with iron from the steel can. The metal outer layer of the mould provided by the present invention does not come into contact with the component and therefore does not contaminate the component.

Claims

What we claim is:

1. A method of constructing a mould for use in a Hot Isostatic Press, comprising the steps of:
5 obtaining a three-dimensional pattern;
forming a ceramic shell around said three-dimensional pattern; and
covering said ceramic shell in a metal layer.
2. A method of constructing a mould according to claim 1, further
10 including the step of removing said pattern from inside said ceramic shell,
such that a cavity is left within said ceramic shell.
3. A method of constructing a mould according to claim 2, wherein
15 said mould is formed with an inlet duct to facilitate the feeding of a feed
material into said cavity.
4. A method of constructing a mould according to claim 3, wherein
said inlet duct comprises a metal tube encased in said ceramic shell.
- 20 5. A method of constructing a mould according to claim 4,
including the step of welding said metal layer to said metal tube.
6. A method of constructing a mould according to claim 1,
including the step of bonding said metal layer to said ceramic shell.
25
7. A method of constructing a mould according to claim 1, wherein
said ceramic shell is non-uniformly between 1 millimetre and 20 millimetres
in thickness.
- 30 8. A method of constructing a mould according to claim 1, wherein
said metal layer is between 0.10 millimetres and 2.00 millimetres in

thickness.

5 **9.** A method of constructing a mould according to claim 1, wherein said metal layer is formed by wrapping said ceramic shell in metal foil and applying heat to said foil to melt it onto said ceramic shell.

10. A method of constructing a mould according to claim 1, wherein said metal layer is formed by sputtercoating metal onto said ceramic shell.

10 **11.** A method of constructing a mould according to claim 1, wherein said metal layer is formed using a vapour deposition process.

12. A method of forming a component in a Hot Isostatic Press, comprising the steps of:

15 obtaining feed material;

 constructing a mould by:

 obtaining a three-dimensional pattern,

 forming a ceramic shell around said three-dimensional pattern,

 removing said pattern from inside said ceramic shell, such that a

20 cavity is left within said ceramic shell, and

 covering said ceramic shell in a metal layer,

 wherein an aperture is defined through said metal layer and said ceramic shell;

 filling said cavity with said feed material via said aperture;

25 sealing the metal around said aperture, such that the mould is impermeable;

 placing said mould inside a Hot Isostatic Press and subjecting said mould to high temperature and isostatic gas pressure;

 removing said mould from the Hot Isostatic Press; and

30 removing the finished component from said mould.

13. A mould for forming a component in a Hot Isostatic Press, comprising:

a ceramic shell; and

a metal layer covering said ceramic shell.

5

14. A mould according to claim 13, wherein said ceramic shell defines a cavity.

15. A mould according to claim 14, further comprising an inlet duct to facilitate the feeding of a feed material into said cavity.

10

16. A mould according to claim 15, wherein said inlet duct comprises a metal tube encased in said ceramic shell.

15

17. A mould according to claim 18, wherein said metal layer is welded to said metal tube.

18. A mould according to claim 15, further comprising one or more further inlet ducts.

20

19. A mould according to claim 13, wherein said ceramic shell is formed around a pre-formed component.

20. A mould according to claim 13, wherein said metal layer is bonded to said ceramic shell.

25

21. A mould according to claim 13, wherein said ceramic shell is between 1 millimetre and 20 millimetres in thickness.

30

22. A mould according to claim 13, wherein said metal layer is between 0.10 millimetres and 2.00 millimetres in thickness.

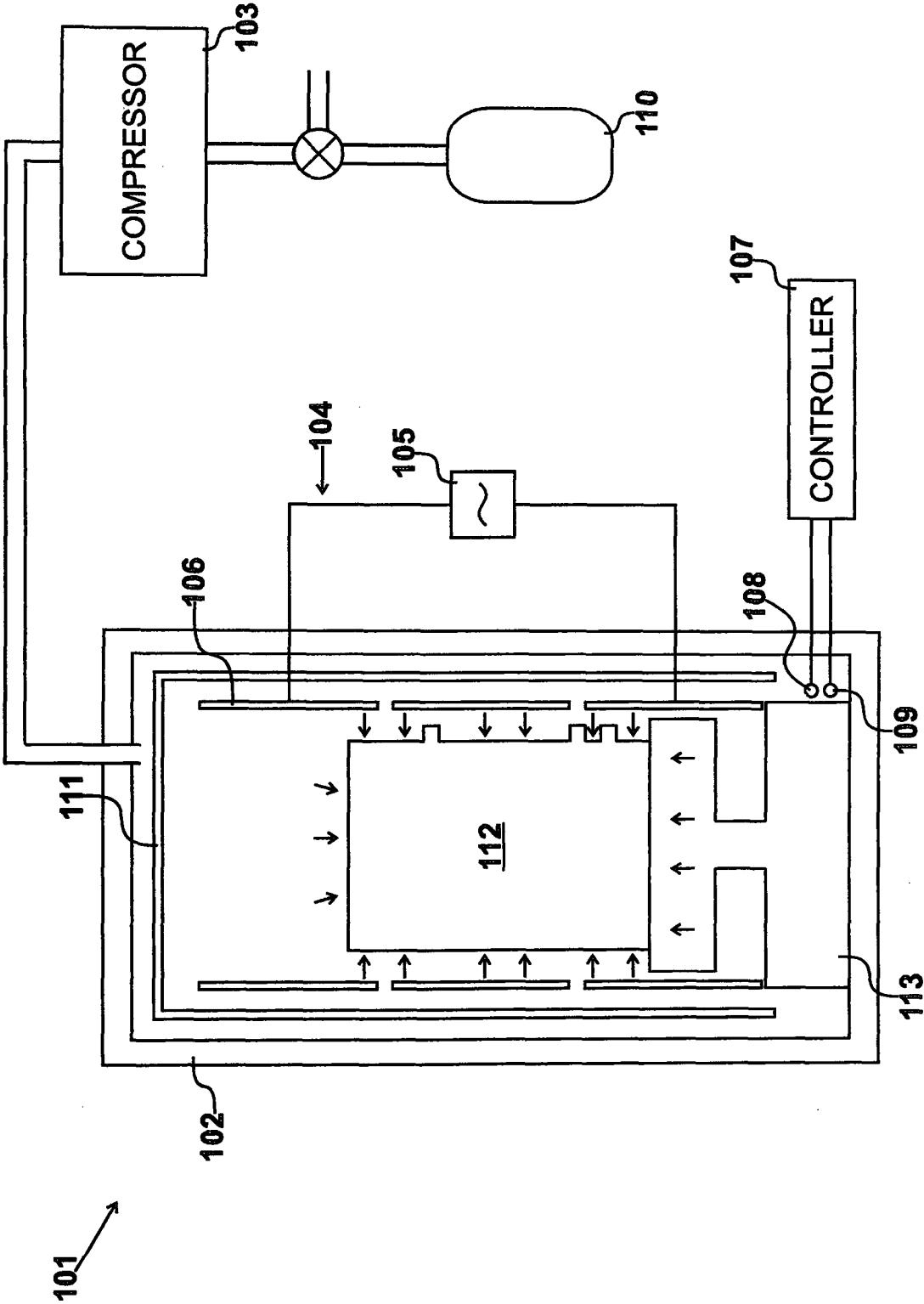


Fig. 1

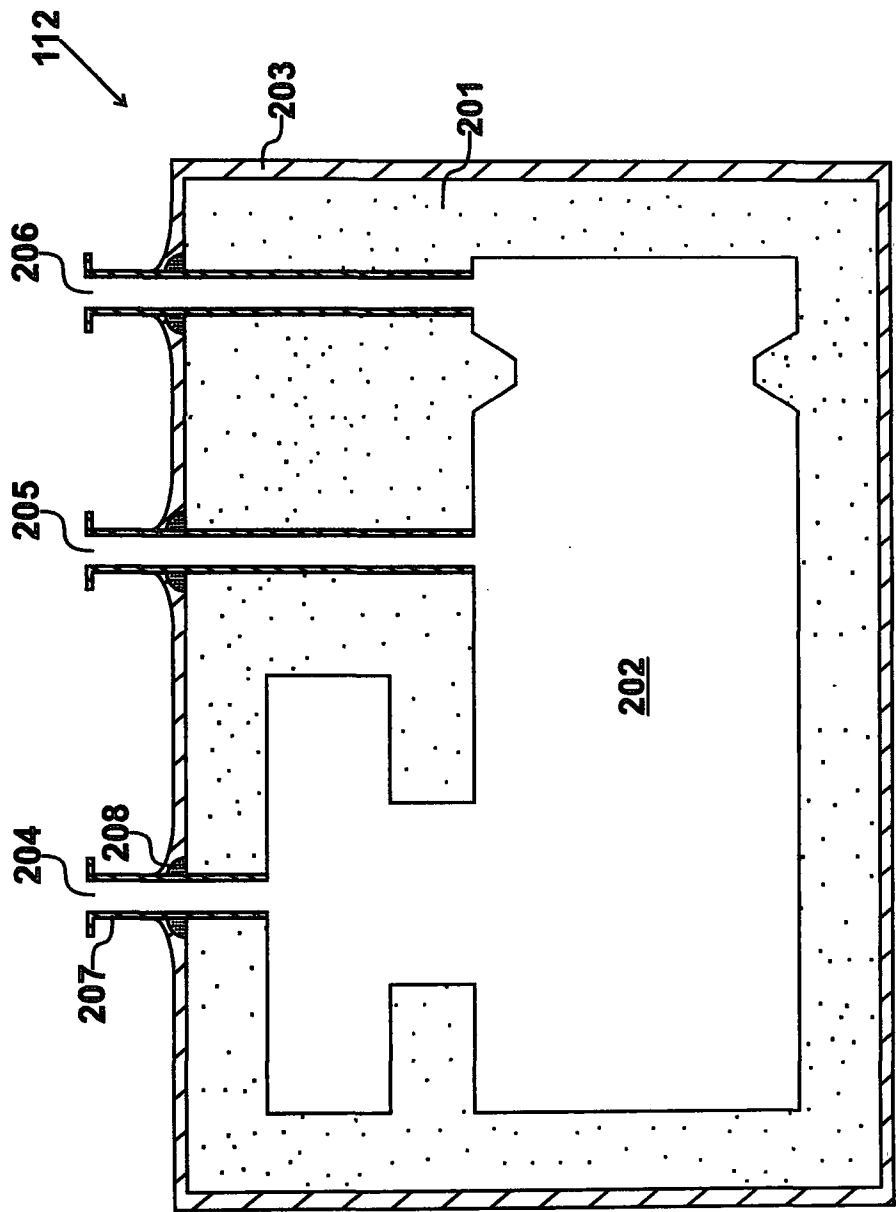
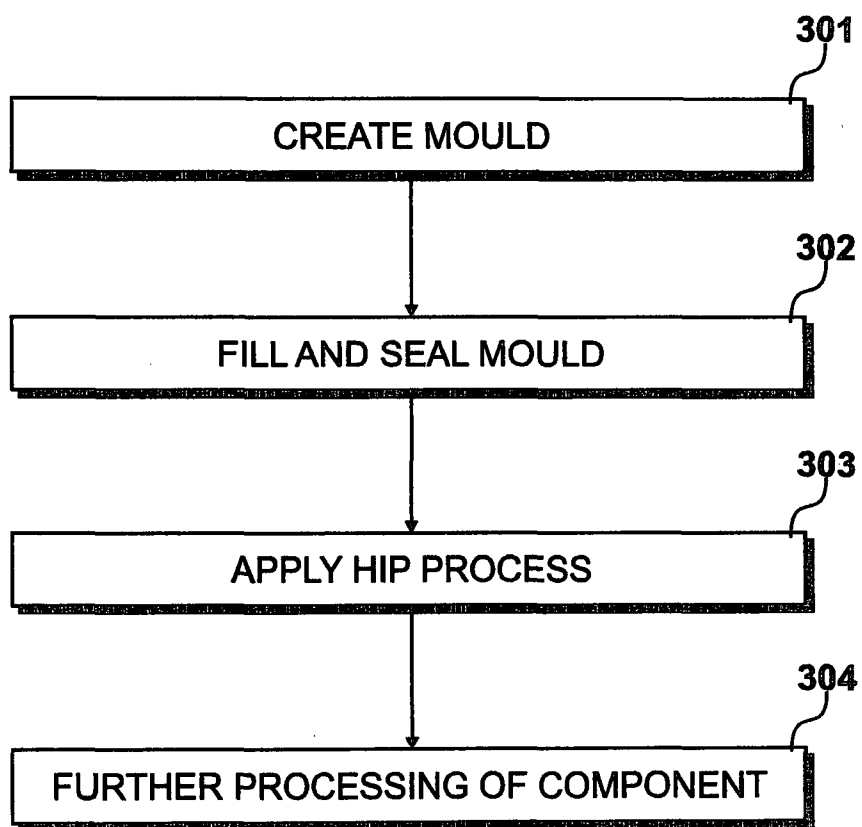


Fig. 2

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*Fig. 3*

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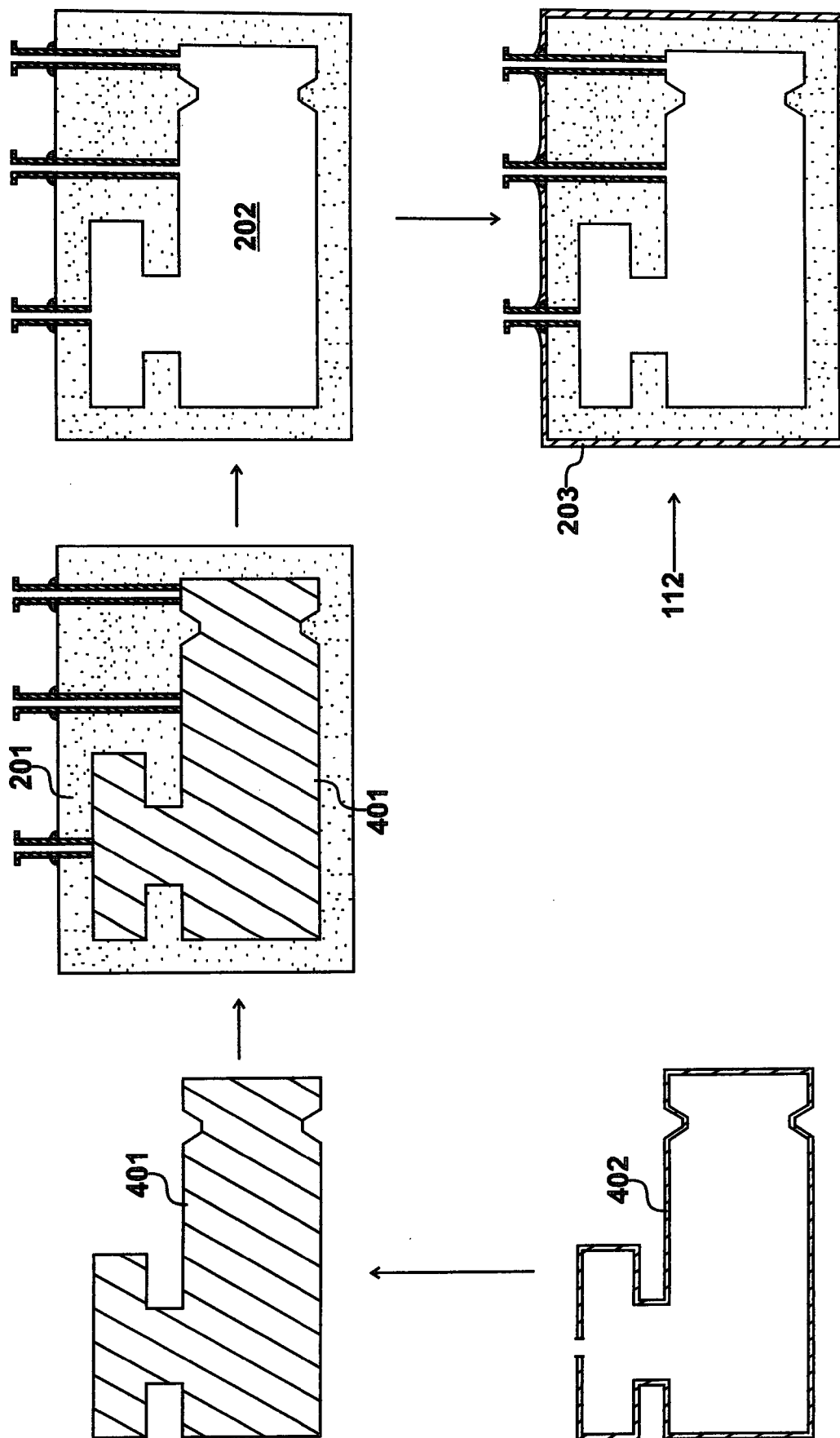
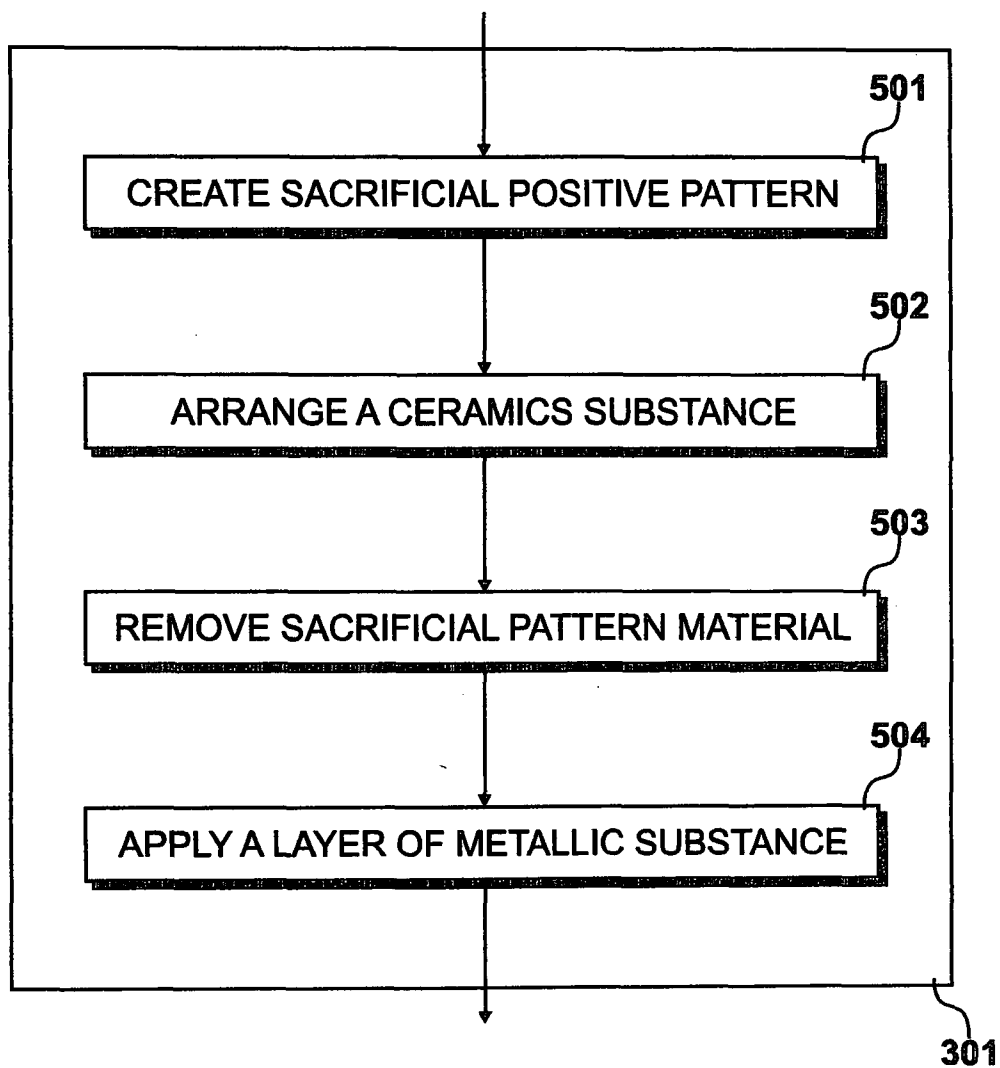
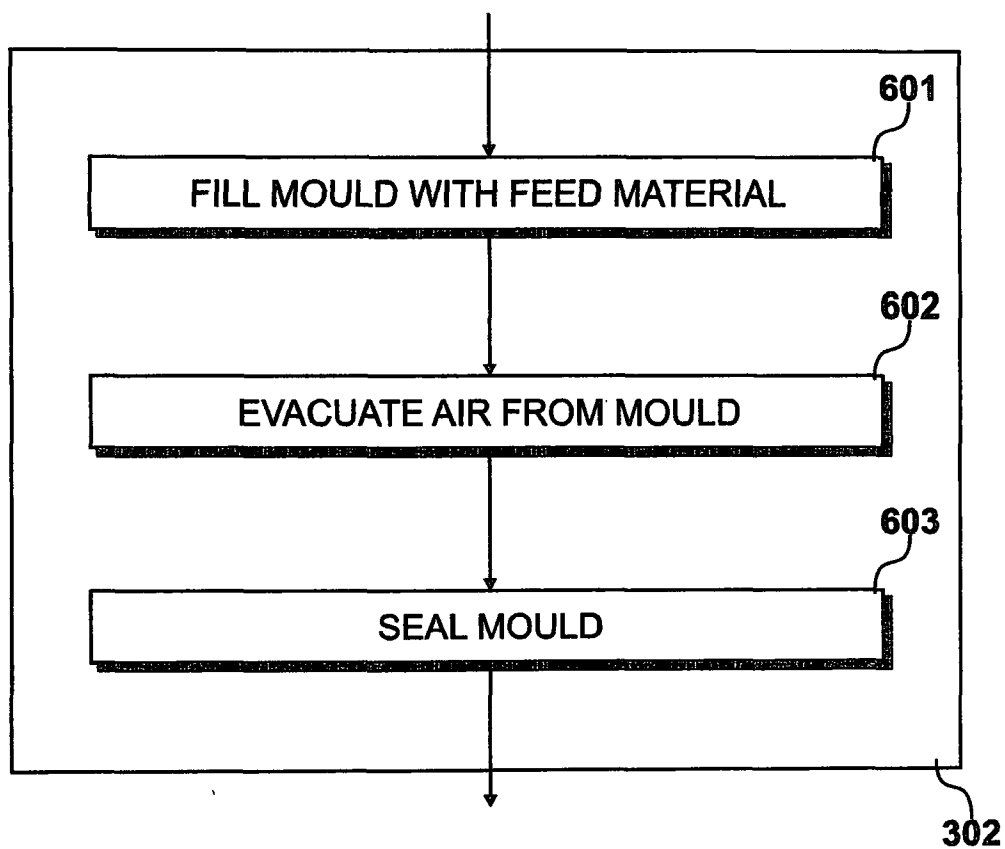


Fig. 4

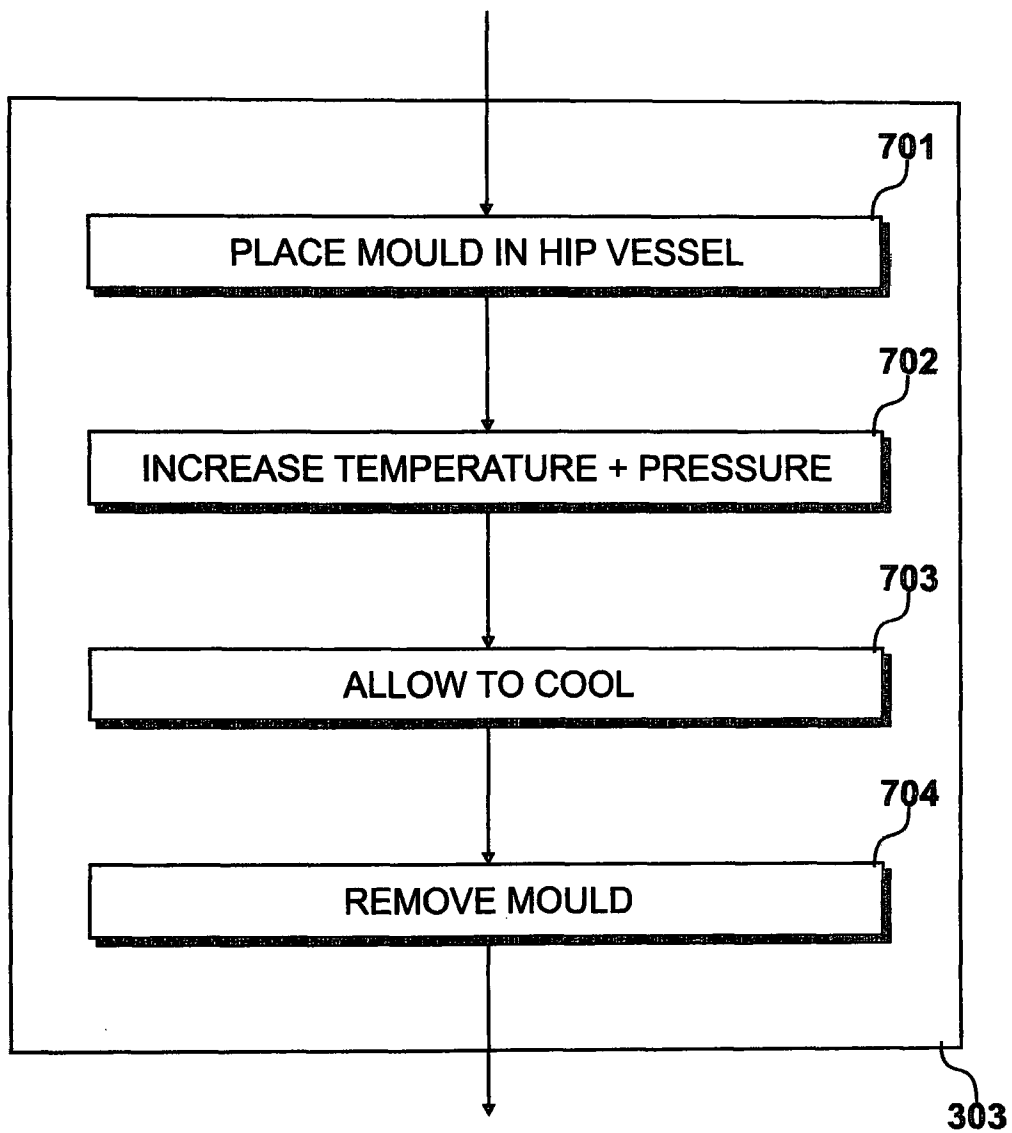
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*Fig. 5*

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*Fig. 6*

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*Fig. 7*

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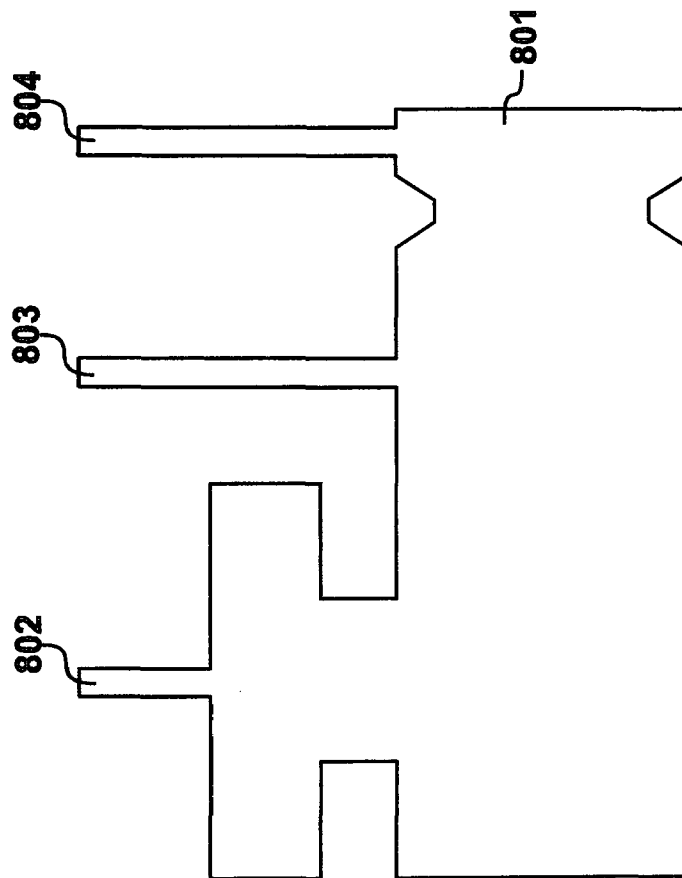


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2015/000255

A. CLASSIFICATION OF SUBJECT MATTER INV. B22C9/02 B22F3/12 B22F3/15 B22F5/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) B22C B22F		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 053 753 A1 (KRUPP GMBH [DE]) 16 June 1982 (1982-06-16) page 1, lines 2-5 page 2, line 10 - page 7, line 10 figure	1-22
X	DE 30 10 299 B1 (MTU MUENCHEN GMBH [DE]) 13 November 1980 (1980-11-13) the whole document	1-3, 12-15
A	DE 41 17 415 A1 (KOBE STEEL LTD [JP]) 13 February 1992 (1992-02-13) column 1, lines 3-16 column 6, lines 47-63 figures 1-13	1-22
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 22 October 2015		Date of mailing of the international search report 29/10/2015
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Stocker, Christian

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2015/000255

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