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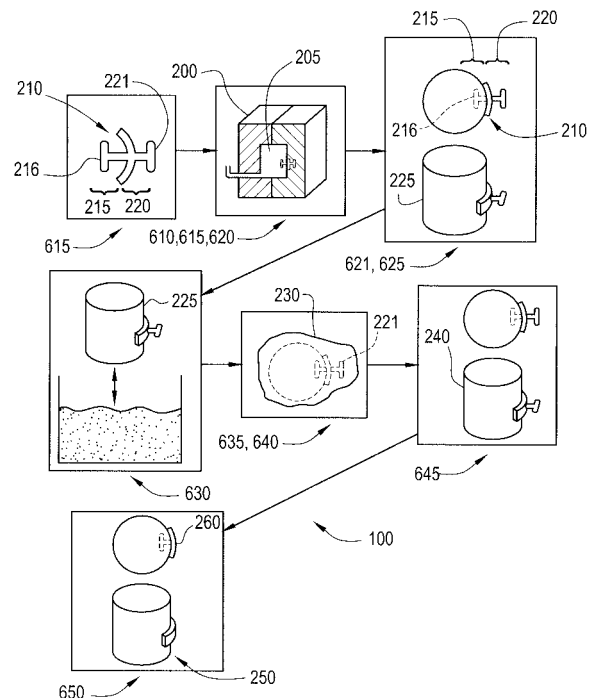
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(54) **Investment cast article and method of production thereof**

(57) A method for manufacturing an investment cast article (250) is disclosed. The method comprises positioning (621) an insert (210) relative to a sacrificial form (225), the insert (210) comprising a first portion (215) and a second portion (220), the first portion (215) being disposed inside the sacrificial form (225) and the second portion (220) being disposed outside the sacrificial form (225). The sacrificial form (225) and the second portion (220) of the insert (210) are coated (630) with a material, forming a shell (230) surrounding the sacrificial form (225) and the second portion (220) of the insert (210). The sacrificial form (225) is evacuated (635) from the shell (230), followed by introducing (640) molten metal into the evacuated shell (230), thereby providing a metal form, and resulting in the first portion (215) of the insert (210) being disposed and bonded inside the metal form. The shell (230) is removed (645) from the metal form (240) and the second portion (220) of the insert (210), thereby resulting in the metal form (240) with the first portion (215) of the insert (210) disposed and bonded therein.

FIG. 1



Description

BACKGROUND OF THE INVENTION

[0001] The present disclosure relates generally to investment casting methods, and particularly to investment casting of turbine airfoils.

[0002] A gas turbine airfoil operates in a high temperature environment. Different parts of the airfoil are subject to different stresses and temperatures. Accordingly, the application requirements of the different parts of the airfoil may conflict with one another. The turbine airfoil is often made of a single material. Selection of the single material to ensure that all parts of the airfoil will have adequate durability is a challenge that includes a substantial degree of engineering.

[0003] The material choice tends to be a balance between all the required material characteristics of the airfoil. More specifically, differing application requirements of local areas of the airfoil typically require material properties different than those of the base material. For example, some areas such as the airfoil tip region or trailing edge, operate at higher temperatures, and will therefore benefit from the use of materials that provide increased oxidation resistance. Other areas, such as the tip shroud contact surfaces or angle wing surfaces will benefit from the use of hard materials to reduce wear. Additionally, strength, creep fatigue, and cyclic fatigue are factors that are considered as part of the material selection.

[0004] Turbine airfoils that operate in gas turbines may be manufactured using an investment casting process. The casting material is often a high strength alloy of nickel, cobalt, or a combination thereof. The specific material choice is an engineering choice to ensure that the airfoil has the desired life given the different stresses and temperatures to which the part may be subjected in use.

[0005] For parts of the airfoil that require different material properties than the base alloy, the general past practice has been to use coatings (such as wear and oxidation resistant coatings) or to use channels within the airfoil to provide preferential cooling. Another approach is to attach surfaces having material properties selected for specific airfoil locations onto the airfoil. Coatings increase manufacturing cost and cycle time and may have a finite durability. Preferential cooling may lead to reduced engine performance. Because of difficulties associated with welding to the airfoil base materials, until recently brazing was the only option to attach surfaces to an airfoil. Welding advances have provided some options to weld otherwise unweldable alloys. However, the use of attached surfaces increases manufacturing cost and cycle time. Accordingly, there is a need in the art for an investment casting method that overcomes these drawbacks.

BRIEF DESCRIPTION OF THE INVENTION

[0006] An embodiment of the invention includes a

method for manufacturing an investment cast article. The method comprises positioning an insert relative to a sacrificial form, the insert comprising a first portion and a second portion, the first portion being disposed inside the sacrificial form and the second portion being disposed outside the sacrificial form. The sacrificial form and the second portion of the insert are coated with a material, forming a shell surrounding the sacrificial form and the second portion of the insert. The sacrificial form is evacuated from the shell, followed by introducing molten metal into the evacuated shell, thereby providing a metal form, and resulting in the first portion of the insert being disposed and bonded inside the metal form. The shell is removed from the metal form and the second portion of the insert, thereby resulting in the metal form with the first portion of the insert disposed and bonded therein.

[0007] Another embodiment of the invention includes a gas turbine airfoil produced according to the method of positioning an insert relative to a sacrificial form, the insert comprising a first portion and a second portion, the first portion being disposed inside the sacrificial form and the second portion being disposed outside the sacrificial form. The sacrificial form and the second portion of the insert are coated with a material, forming a shell surrounding the sacrificial form and the second portion of the insert. The sacrificial form is evacuated from the shell, followed by introducing molten metal into the evacuated shell, thereby providing a metal form, and resulting in the first portion of the insert being disposed and bonded inside the metal form. The shell is removed from the metal form and the second portion of the insert, thereby resulting in the metal form with the first portion of the insert disposed and bonded therein. One or more of the second portion of the insert and the metal form is machined, thereby providing the turbine airfoil.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Referring to the exemplary drawings wherein like elements are numbered alike in the accompanying Figures:

Figure 1 depicts in pictorial form an exemplary embodiment of a method for investment casting in accordance with embodiments of the invention;

Figure 2 depicts in flowchart form an exemplary embodiment of a method for investment casting in accordance with embodiments of the invention;

Figure 3 depicts in flowchart form a generalized exemplary embodiment of a method for investment casting in accordance with embodiments of the invention;

Figure 4 depicts a front perspective view of an exemplary embodiment of a turbine airfoil manufactured in accordance with embodiments of the inven-

tion; and

Figure 5 depicts a front view of an exemplary embodiment of a turbine airfoil manufactured in accordance with embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0009] An embodiment of the invention provides a method to produce investment cast parts that have inserts embedded within the cast structure. By incorporating inserts, a part produced by the investment cast process may have multiple, optimized material properties, strategically located to provide desired application characteristics such as increased resistance to localized wear, oxidation, corrosion, and elevated temperature exposure.

[0010] Another embodiment of the invention optimizes the material properties in local areas of investment cast turbine airfoils using cast preforms, or inserts. The inserts are made of specific materials having characteristics suited to the environmental exposure of the particular, localized portion of the airfoil in which the insert is placed. These preforms can be made from different materials than the base airfoil alloy. Multiple preforms of different materials are contemplated on a single airfoil. The preforms are joined to the airfoil during the investment casting process and become an integral part of the airfoil. The joining process can involve one or both of a mechanical bond and a metallurgical bond.

[0011] Further, it is contemplated that an embodiment of the invention will provide a reduction in manufacturing steps. Following the investment casting of an airfoil, the current practice to attach a surface to the base material is to machine the airfoil location to which the surface will be applied, braze or weld the surface in place, machine the surface, and then heat treat the assembly. An embodiment of the invention provides an investment cast airfoil with a cast-in secondary surface, thereby requiring only a single machining operation.

[0012] As a result of the investment casting process, the cast preforms become an integral part of the airfoil casting. The airfoil then has different material properties and/or structures to provide optimized characteristics tailored to the application requirements of the specific regions of the part. In this way, subsequent coatings may be eliminated, as well as the need to provide local cooling flow.

[0013] Referring to Figure 1 in conjunction with Figure 2, an embodiment of an exemplary investment casting process is depicted. A pictorial chart 100 and a flowchart 600 depict exemplary steps to provide an investment cast part 250, such as a turbine airfoil for example, containing a machined insert 260, which is machined subsequent to casting. In an embodiment, the machined insert 260 provides material properties suited to application requirements that relate to the location of the machined insert 260 within the airfoil.

[0014] The process begins with locating 610 a die 200, the die 200 having a cavity 205. The next step is positioning 615 an insert 210 relative to the die 200. The insert 210 has a first portion 215 and a second portion 220, each portion 215, 220 including a mechanical retention feature 216, 221 to provide alignment and retention of the insert 210, as will be described further below. The cavity 205 of the die 200 is larger than the first portion 215 of the insert 210, thereby allowing the first portion 215 of the insert 210 to be disposed inside the cavity 205.

[0015] The next process step is positioning 615 the insert 210 such that the first portion 215 of the insert 210 is disposed inside the cavity 205, and the second portion 220 of the insert 210 is disposed outside the cavity 205, and captivated by the die 200. In an embodiment, the position of the insert 210 shall be selected based upon the material characteristic requirements of the application for the investment cast part 250. After the insert 210 has been properly positioned 615 within the die 200, introducing 620, such as injecting for example, molten filler, such as wax or plastic for example, into the cavity 205 creates a sacrificial form 225. In an embodiment, the molten filler will be bonded to the first portion 215 of the insert 210. The mechanical retention feature 216 is configured to secure the retention and position of the insert 210 relative to the sacrificial form 225.

[0016] Following the introducing 620 molten filler into the die 200, the method proceeds by removing 625 the sacrificial form 225 and the insert 210 from the die 200. The second portion 220 of the insert 210 is disposed outside of the sacrificial form 225, while the first portion 215 is disposed and bonded inside the sacrificial form 225, as described above.

[0017] Next is coating 630 the sacrificial form 225 and the second portion 220 of the insert 210 with a refractory material, such as powdered silica. In an embodiment, the sacrificial form 225 and the insert 210 are dipped in a slurry, which coats the sacrificial form 225, forming a skin. The skin is dried and the process of dipping and drying is repeated until the refractory material forms a shell 230 thick enough to provide the necessary structural support for the molten metal, as will be discussed further below. The material forms the shell 230 surrounding the sacrificial form 225 and the second portion 220 of the insert 210. After sufficient time to allow the shell 230 to dry and solidify, heat is applied to melt the filler, thereby evacuating 635 the sacrificial form 225 from the shell 230. Upon evacuation 635 of the filler, the geometry of the sacrificial form 225 is contained by the interior of the empty shell 230. Similar to the mechanical retention feature 216 of the first portion 215, it may be appreciated that the mechanical retention feature 221 of the second portion 220 is configured and disposed to secure the retention and position of the insert 210 relative to the shell 230. In this way, both mechanical retention features 216, 221 secure the position of the insert 210 relative to the investment cast part 250, allowing the position of insert 210 relative to the investment cast part 250 to remain fixed throughout

the various steps of the process 100, 600.

[0018] While an embodiment of the invention has been described using a refractory material of powdered silica, it will be appreciated that the scope of the invention is not so limited, and that the invention may also apply to shells made from other materials such as, but not limited to, plaster of paris, alumina-silicate, and ethyl silicate, for example. While an embodiment of the invention has been described depicting an insert with a bulb-shaped mechanical retention feature, it will be appreciated that the scope of the invention is not so limited, and that the invention may also apply to inserts using alternate means of mechanical retention, such as a thread, a knurl, a groove, and a step, for example.

[0019] In an embodiment, the shell 230 is pre-heated to drive off any remaining filler material, and to prevent possible cracks as a result of thermal shock from the high temperature of the molten metal. Preheating is followed by introducing 640 molten metal into the evacuated shell 230, thereby providing a metal form 240. It will be appreciated that the multiple layers described above are configured to provide the shell 230 with the appropriate structural strength, capable to support the weights and forces resulting from the introduction 640 of the molten metal. The introduction 640 of the molten metal may occur while the shell 230 and the molten metal are subject to a vacuum, in order to extract evolved gasses and reduce oxidation, thereby increasing the quality of the metal form 240. Subsequent to introducing 640 molten metal, the first portion 215 of the insert 210 will be bonded inside the metal form 240. The bond between the metal form 240 and the first portion 215 may be one or both of a mechanical bond, as provided by the mechanical retention feature 216, and a metallurgical bond, resulting from diffusion between the material of the insert 210 and the material of the metal part 240.

[0020] After sufficient time to allow the metal form 240 to cool, the next step is removing 645 the shell 230 from the metal form 240 and the second portion 220 of the insert 210. In an embodiment, the shell 230, which is typically brittle, may be removed via mechanical vibration, high-pressure steam, chemical cleaners, or a combination thereof. Other removal methods may be employed while still keeping within the scope of the invention.

[0021] It will be appreciated that the geometry of the metal form 240, which is provided by the interior of the shell 230 from which the sacrificial form 225 has been evacuated, is directly related to the geometry of the die 200 that was used to produce the sacrificial form 225. Factors such as thermal expansion and contraction of the filler, the shell material, and the metal will affect the final metal form 240 geometry, and are therefore considered in the configuration of the die 200.

[0022] Because the insert 210 is disposed bonded within the metal form 240, there is no longer a need for the mechanical retention feature 221 of the second portion 220. Therefore, subsequent to the removing 645 of

the shell 230, machining 650 the second portion 220 of the insert 210 may be done to remove the mechanical retention feature 221, providing a machined insert 260. In an embodiment, the machined insert 260 shall be configured to provide the geometric tolerances and features required by the application in which the investment cast part 250 is used. The metal form 240 may also be machined 650 to provide the geometric tolerances and features of the investment cast metal part 250 required by the application.

[0023] A more general sense of the method depicted in Figure 2 by flowchart 600 may be represented by the method depicted in Figure 3 by flowchart 700, where like elements are numbered alike. In the flowchart 700, positioning 621 of the insert 210 relative to the sacrificial form 225 may occur without the need to create the sacrificial form 225 within a die 200, as described above. For example, the sacrificial form 225 may be provided as a machined wax or plastic form, and the insert 210 may be embedded into the sacrificial form 225 by vibratory or other suitable action.

[0024] Referring now to Figures 4 and 5, an exemplary embodiment of a gas turbine airfoil 300 is depicted. Using the process 100, 600 described above, it is contemplated that subsequent to the machining 650 of one or more of the second portion 220 of the insert 210 and the metal form 240, the turbine airfoil 300 may be produced.

[0025] In an embodiment, various locations of the gas turbine airfoil 300 may utilize the insert 210 to provide improved material characteristics. Between Figures 4 and 5, a tip shroud edge 305, tip shroud contact surfaces 310, an airfoil tip 315, a leading edge 320, a trailing edge 325, a platform edge 330, and angle wings 335 are depicted. It will be appreciated that each location described above as part of the airfoil 300 has a corresponding position within the cavity 205 of the die 200 configured to produce the sacrificial form 225. Further, it will be appreciated that each such position of the die 200 may be configured to receive the insert 210. Accordingly, the positioning 615 the insert 210 into the die 200 may include positioning 615 one or more inserts 210 at positions of the die 200 corresponding to the airfoil 300 locations described above. In an embodiment, the first portion 215 of the machined insert 260, disposed inside the airfoil 300, is retained by one or more of a mechanical bond and a metallurgical bond.

[0026] In an embodiment of the invention, it is contemplated that each location described above may utilize an insert 210 comprising materials that are suited for the conditions to which that location is exposed. It is contemplated that the machined insert 260 at the airfoil tip 315 may be configured to provide one or more of improved oxidation and wear properties. It is further contemplated that the machined insert 260 at one or more of the trailing edge 325 and the leading edge 320 may be configured to provide improved oxidation properties. The machined inserts 260 at one or more of the tip shroud contact surfaces 310 and the angle wing surfaces 335 may be con-

figured to provide improved wear properties. The machined inserts 260 at one or more of the platform edge 330 and the tip shroud edge 305 surfaces are contemplated to be configured to provide improved corrosion properties.

[0027] Materials that may provide characteristics pertinent to the localized application needs of the gas turbine airfoil 300, such as high temperature, oxidation, wear, and corrosion resistance include, but are not limited to, tungsten carbide and molybdenum. Accordingly, in an embodiment, the positioning 615 the insert 210 may include inserts 210 made of materials comprising one or more of tungsten carbide and molybdenum. The exact composition of the insert 210 selected for use will be related to the melting temperature of the casting metal. For example, it is contemplated to be beneficial to utilize an insert 210 that has a melting temperature greater than the melting temperature of the casting material, to avoid melting of the insert 210 in response to the introducing 640 of the molten casting material to the shell 230. In an embodiment, pre-heating of the shell 230 may be performed at between 1700 to 2000 degrees Fahrenheit (927 to 1093 degrees Centigrade) prior to the introduction of molten metal alloy into the shell 230. It is contemplated that positioning 615 the insert 210 with plating comprising one or more of platinum and palladium will reduce oxidation of the inserts 210 at such elevated temperatures. Finally, the introducing 640 molten metal is contemplated to include investment casting materials that are well suited to the high temperatures present within the application of a gas turbine airfoil 300, such as alloys having one or more of nickel and cobalt.

[0028] As disclosed, some embodiments of the invention may include some of the following advantages: regions of an investment casting that possess material properties optimized for application requirements; a turbine airfoil with application-specific inserts; a turbine airfoil that may be produced without coatings or thermal cooling passages; and the ability to produce a turbine airfoil having application-specific surfaces using fewer manufacturing steps.

[0029] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best or only mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Also, in the drawings and the description, there have been disclosed exemplary embodiments of the invention and, although specific terms may have been employed, they are unless otherwise stated used in a generic and descriptive sense

only and not for purposes of limitation, the scope of the invention therefore not being so limited. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

Claims

1. A method for manufacturing an investment cast article (250), the method comprising:

positioning (621) an insert (210) relative to a sacrificial form (225), the insert (210) comprising a first portion (215) and a second portion (220), the first portion (215) being disposed inside the sacrificial form (225) and the second portion (220) being disposed outside the sacrificial form (225);

coating (630) the sacrificial form (225) and the second portion (220) of the insert (210) with a material, the material forming a shell (230) surrounding the sacrificial form (225) and the second portion (220) of the insert (210);

evacuating (635) the sacrificial form (225) from the shell (230);

introducing (640) molten metal into the evacuated shell (230), thereby providing a metal form (240), and resulting in the first portion (215) of the insert (210) being disposed and bonded inside the metal form (240); and

removing (645) the shell (230) from the metal form (240) and the second portion (220) of the insert (210), thereby resulting in the metal form (240) with the first portion (215) of the insert (210) disposed and bonded therein.

2. The method of Claim 1, wherein:

the introducing (640) molten metal occurs while the shell (230) and the molten metal are subject to a vacuum.

3. The method of Claim 1 or Claim 2, wherein the positioning (621) comprises:

positioning (621) the insert comprising mechanical retention features (216).

4. The method of Claim 1, wherein:

the manufacturing comprises manufacturing an investment cast gas turbine airfoil (300);
the positioning further comprises:

- positioning (615) the insert (210) relative to a die (200) having a cavity (205) larger than the first portion (215) of the insert (210), such that the first portion (215) of the insert (210) is disposed inside the cavity (205), and the second portion (220) of the insert (210) is disposed outside the cavity (205) and captivated by the die (200);
 introducing (620) molten filler into the cavity (205) to create the sacrificial form (225), resulting in the filler being bonded to the first portion (215) of the insert (210);
 removing (625) the sacrificial form (225) and the insert (210) from the die (200), the second portion (220) of the insert (210) disposed outside the sacrificial form (225), thereby providing the sacrificial form (225) and the insert (210);
 the die cavity (205) has a plurality of positions that correspond to an airfoil tip (315), an airfoil leading edge (320), an airfoil trailing edge (325), airfoil tip shroud contact surfaces (310), airfoil angle wings (335), an airfoil platform edge (330), and an airfoil tip shroud edge (305); and
 the positioning (615) comprises positioning (615) one or more inserts (210) at the positions of the die cavity (205) corresponding to one or more of the airfoil tip (315), the airfoil leading edge (320), the airfoil trailing edge (325), the airfoil tip shroud contact surfaces (310), the airfoil angle wings (335), the airfoil platform edge (330), and the airfoil tip (315) shroud edge (305).
5. A gas turbine airfoil (300) produced according to the method of:
- positioning (621) an insert (210) relative to a sacrificial form (225), the insert (210) comprising a first portion (215) and a second portion (220), the first portion (215) being disposed inside the sacrificial form (225) and the second portion (220) being disposed outside the sacrificial form (225);
 coating (630) the sacrificial form (225) and the second portion (220) of the insert (210) with a material, the material forming a shell (230) surrounding the sacrificial form (225) and the second portion (220) of the insert (210);
 evacuating (635) the sacrificial form (225) from the shell (230);
 introducing (640) molten metal into the evacuated shell (230), thereby providing a metal form (240), and resulting in the first portion (215) of the insert (210) being disposed and bonded inside the metal form (240); and
 removing (645) the shell (230) from the metal form (240) and the second portion (220) of the insert (210), thereby resulting in the metal form (240) with the first portion (215) of the insert (210) disposed and bonded therein;
 machining (650) one or more of the second portion (220) of the insert (210) and the metal form (240), thereby providing the turbine airfoil (300).
6. The gas turbine airfoil (300) of Claim 5, wherein:
- the insert (210) comprises mechanical retention features (216).
7. The gas turbine airfoil (300) of Claim 5, wherein:
- the first portion (215) of the machined insert (260) is retained by one or more of a mechanical bond and a metallurgical bond.
8. The gas turbine airfoil (300) of Claim 5, wherein:
- the airfoil (300) is made from an alloy of nickel, cobalt, or a combination thereof; and
 the insert (210) is made from a material to provide characteristics pertinent to localized application needs of the gas turbine airfoil (300) including at least one of temperature, oxidation, wear, and corrosion resistance.
9. The gas turbine airfoil (300) of Claim 5, comprising:
- an airfoil tip (315), an airfoil leading edge (300), an airfoil trailing edge (325), airfoil tip (315) shroud contact surfaces (310), airfoil angle wings (335), an airfoil platform edge (330), and an airfoil tip shroud edge (305);
 one or more machined inserts (260) at one or more of the following locations of the airfoil: the airfoil tip (315); the airfoil leading edge (320); the airfoil trailing edge (325); the airfoil tip shroud contact surfaces (310); the airfoil angle wings (335); the airfoil platform edge (330); and the airfoil tip shroud edge (305).
10. The gas turbine airfoil (300) of Claim 5 wherein:
- the melting temperature of the insert (210) is greater than the melting temperature of the metal form (240).

FIG. 1

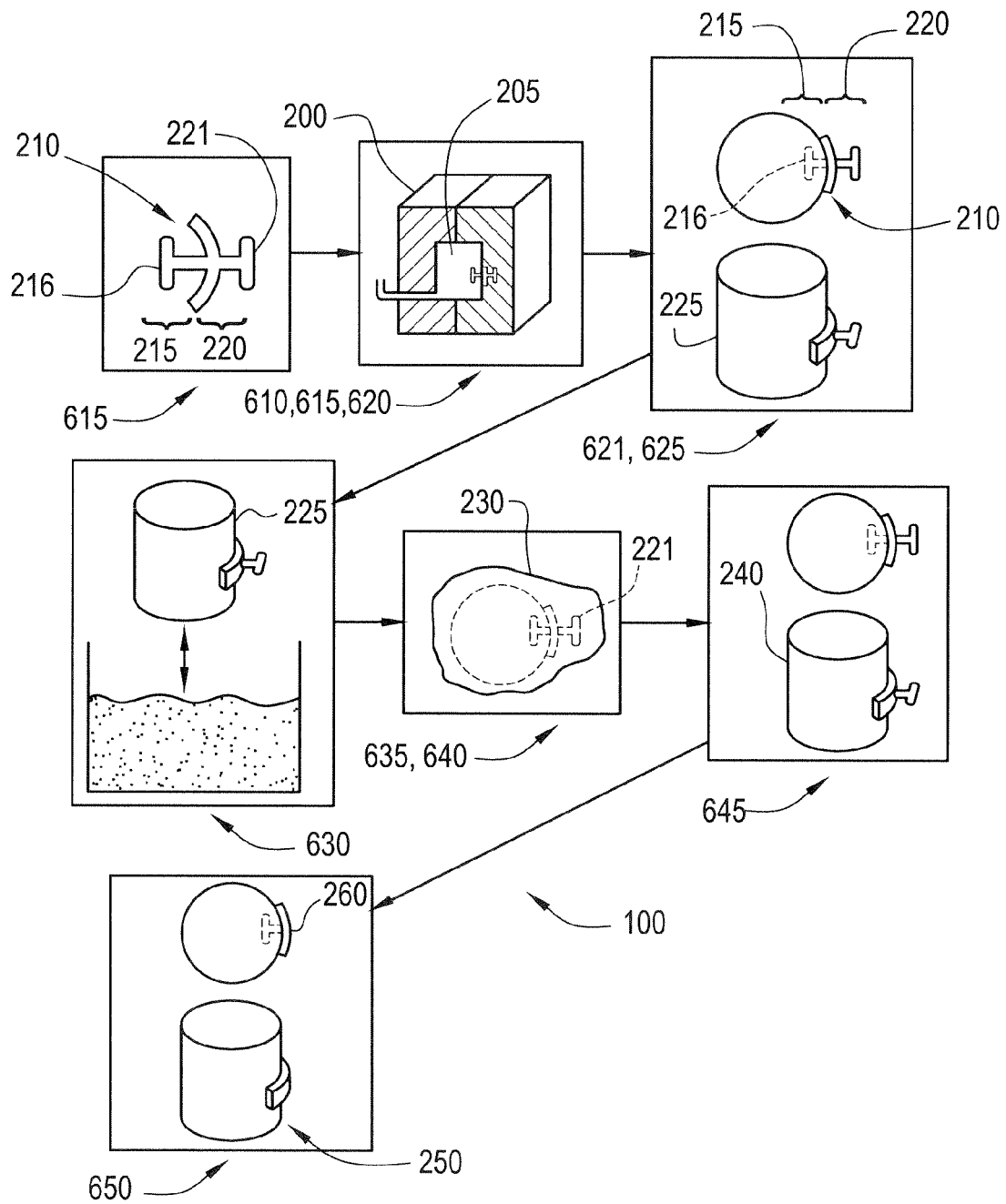


FIG. 2

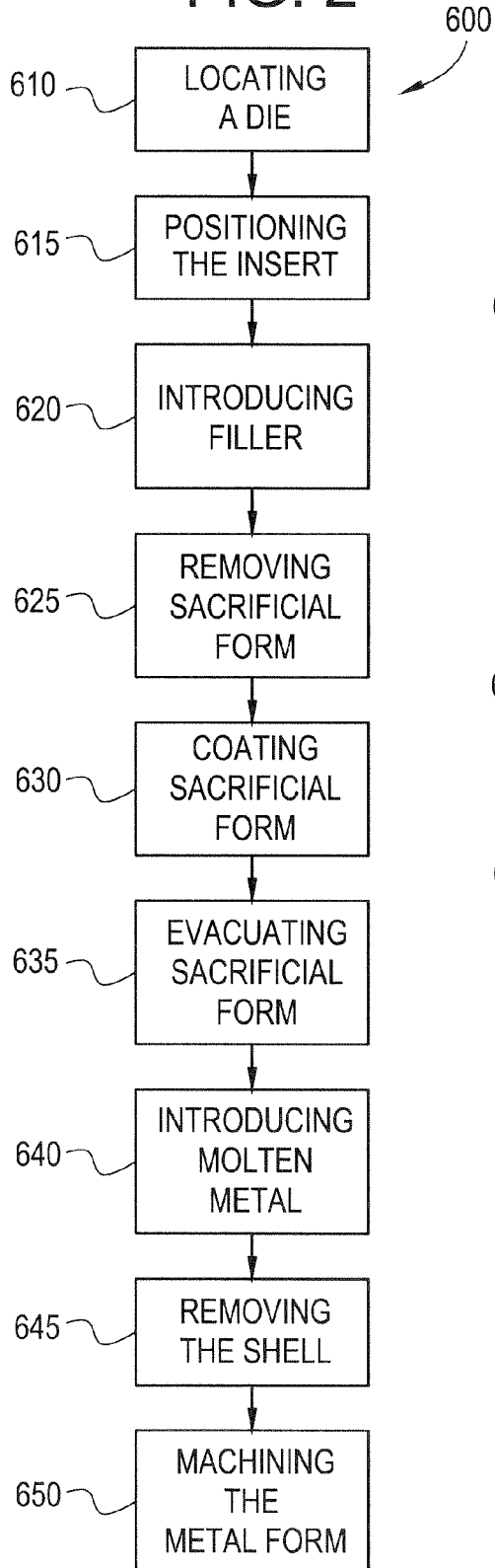


FIG. 3

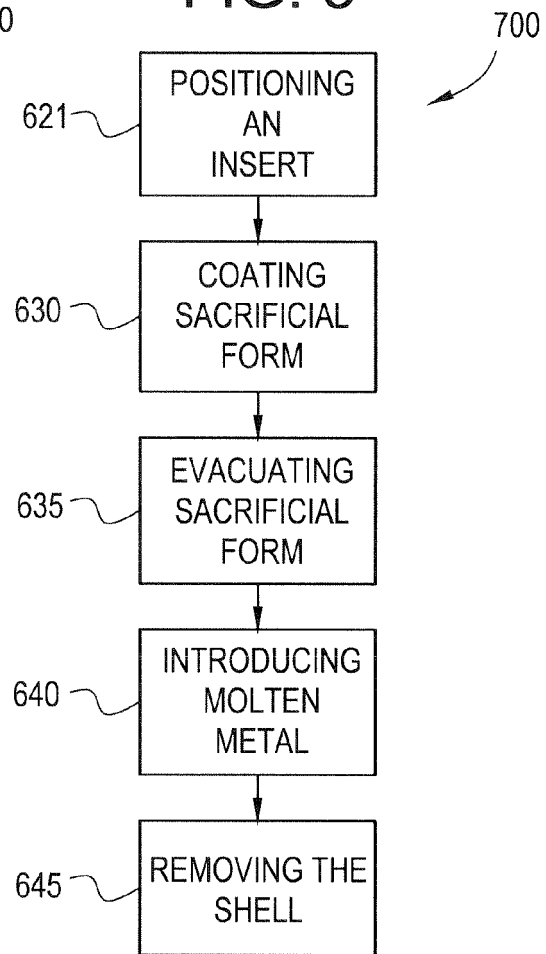


FIG. 4

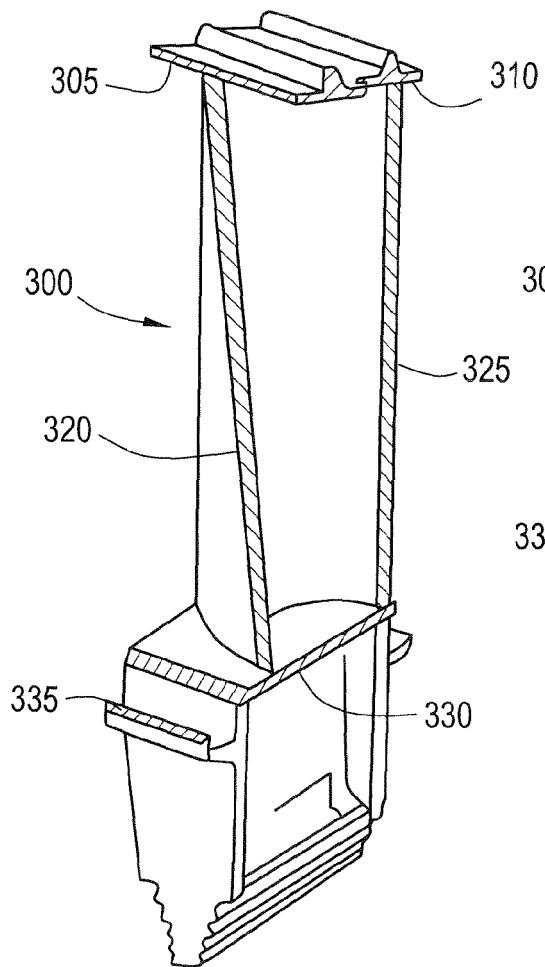
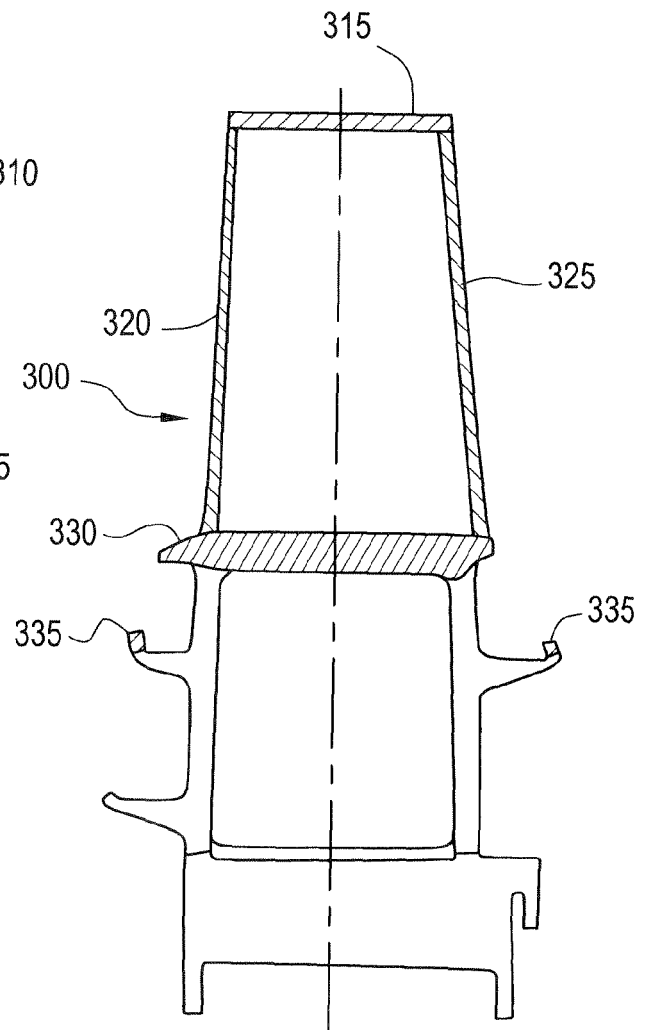


FIG. 5





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 07 10 6279

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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The present search report has been drawn up for all claims			
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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 07 10 6279

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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