



EUROPEAN PATENT APPLICATION

(43) Date of publication:
16.04.2014 Bulletin 2014/16

(51) Int Cl.:
B28B 7/34 (2006.01)

(21) Application number: **13187981.9**

(22) Date of filing: **09.10.2013**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA ME

(72) Inventor: **Bunker, Ronald Scott**
Niskayuna, NY New York 12309 (US)

(74) Representative: **Cleary, Fidelma**
GPO Europe
GE International Inc.
The Ark
201 Talgarth Road
Hammersmith
London W6 8BJ (GB)

(30) Priority: **12.10.2012 US 201213650320**

(71) Applicant: **General Electric Company**
Schenectady, New York 12345 (US)

(54) **Method of making surface cooling channels on a component using lithographic molding techniques**

(57) Methods of casting a component including one or more surface cooling channels. The method including casting (160) a ceramic core into a flexible mold of a core section and casting (162) a ceramic shell in at least two sections into respective flexible molds of a first shell section and a second shell section. A ceramic casting vessel is subsequently formed by assembling (164) the ceramic core within the ceramic shell sections. A metal substrate material is cast into the ceramic casting vessel (166). Removal (168) of the ceramic casting vessel reveals a substrate of the component having defined therein the interior passageway, the one or more cooling passages in fluidic communication with the interior passageway and one or more surface grooves in fluidic communication with the one or more cooling passages.

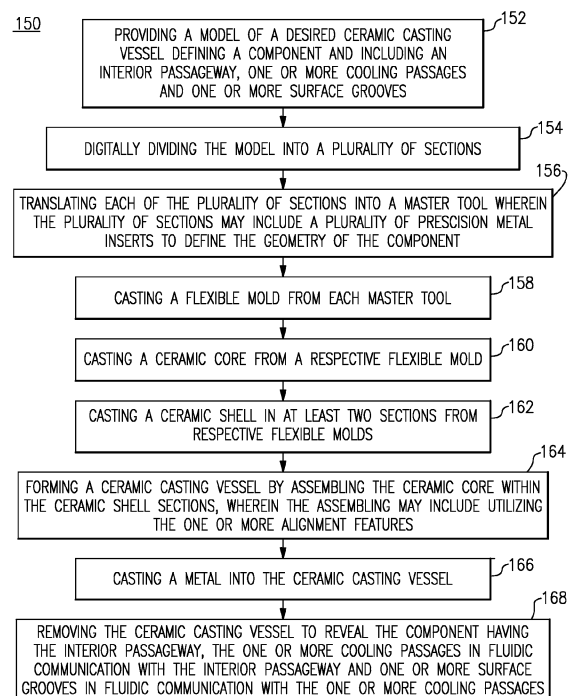


FIG.16

Description

BACKGROUND

[0001] The subject matter disclosed herein relates generally to turbine systems, such as gas turbine systems, and more particularly to micro-channel cooling therein.

[0002] In gas turbine engines, air is pressurized in a compressor and mixed with fuel in a combustor for generating hot combustion gases. Energy is extracted from the gases in a high pressure turbine (HPT), which powers the compressor, and in a low pressure turbine (LPT), which powers a fan in a turbofan aircraft engine application, or powers an external shaft for marine and industrial applications.

[0003] During operation of gas turbine engines, the temperatures of combustion gases may exceed 3,000°F, considerably higher than the melting temperatures of the metal parts of the engine which are in contact with these gases. Operation of these engines at gas temperatures that are above the metal part melting temperatures is a well-established art, and depends in part on supplying a cooling air to the outer surfaces of the metal parts through various methods. The metal parts of these engines that are particularly subject to high temperatures, and thus require particular attention with respect to cooling, are the metal parts forming combustors and parts located aft of the combustor.

[0004] Engine efficiency increases with temperature of combustion gases. However, the combustion gases heat the various components along their flow path, which in turn requires cooling thereof to achieve a long engine lifetime. Typically, the hot gas path components are cooled by bleeding air from the compressor. This cooling process reduces engine efficiency, as the bled air is not used in the combustion process.

[0005] Gas turbine engine cooling art is mature and includes numerous patents for various aspects of cooling circuits and features in the various hot gas path components. For example, the combustor includes radially outer and inner liners, which require cooling during operation. Turbine nozzles include hollow vanes supported between outer and inner bands, which also require cooling. Turbine rotor blades are hollow and typically include cooling circuits therein, with the blades being surrounded by turbine shrouds, which also require cooling. The hot combustion gases are discharged through an exhaust which may also be lined, and suitably cooled.

[0006] In all of these exemplary gas turbine engines components, thin metal walls of high strength superalloy metals are typically used for enhanced durability while minimizing the need for cooling thereof. Various cooling circuits and features are tailored for these individual components in their corresponding environments in the engine. For example, a series of internal cooling passages, or serpentine, may be formed in a hot gas path component. A cooling fluid may be provided to the serpentine

from a plenum, and the cooling fluid may flow through the passages, cooling the hot gas path component substrate and coatings. However, this cooling strategy typically results in comparatively low heat transfer rates and non-uniform component temperature profiles.

[0007] Employing micro-channel cooling techniques has the potential to significantly reduce cooling requirements. Micro-channel cooling places the cooling as close as possible to the heat zone, thus reducing the temperature difference between the hot side and cold side of the load bearing substrate material for a given heat transfer rate. However, current techniques for forming micro-channels typically require the use of post-casting machining to form the micro-channels and coolant feed holes. Post-casting machining involves potentially damaging processes and typically requires long times.

[0008] It would therefore be desirable to provide a method for forming cooling channels in hot gas path components that eliminates the need for the post-casting machining.

BRIEF DESCRIPTION

[0009] In one aspect, the invention resides in a method of casting a component including one or more surface cooling channels. The method includes casting a ceramic core from a flexible mold of one or more core sections and casting a ceramic shell in at least two sections into respective flexible molds of a first shell section and a second shell section. Next, a ceramic casting vessel is formed by assembling the ceramic core within the ceramic shell sections. A metal substrate material is cast into the ceramic casting vessel. Subsequently, the ceramic casting vessel is removed. Removal of the ceramic casting vessel reveals a substrate of the component having defined therein an interior passageway, one or more cooling passages in fluidic communication with the interior passageway and one or more surface grooves in fluidic communication with the one or more cooling passages.

[0010] In another aspect, the invention resides in a method of casting a component including one or more surface cooling channels. The method includes providing a model of a desired ceramic casting vessel defining a geometry of the component and including an interior passageway, one or more cooling passages in fluidic communication with the interior passageway and one or more surface grooves in fluidic communication with the one or more cooling passages. The model is digitally divided into a plurality of sections and each of the plurality of sections is translated into a master tool wherein the plurality of sections include a one or more precision metal inserts to define the geometry of the component including the interior passageway, the one or more cooling passages and the one or more surface grooves and one or more alignment features. A flexible mold is next cast from each master tool. A ceramic core is cast from a respective flexible mold. A ceramic shell is cast in at least two sec-

tions from a respective flexible mold. A ceramic casting vessel is formed by assembling the ceramic core within the ceramic shell sections. Next, a metal is cast into the ceramic casting vessel. The ceramic casting vessel is subsequently removed to reveal a substrate of the component having the interior passageway, the one or more cooling passages in fluidic communication with the interior passageway and one or more surface grooves in fluidic communication with the one or more cooling passages.

[0011] In yet another aspect, the invention resides in a method of casting a component including one or more surface cooling channels is disclosed. The method includes providing a model of a desired ceramic casting vessel defining a geometry of the component and including an interior passageway, one or more cooling passages in fluidic communication with the interior passageway and one or more surface grooves in fluidic communication with the one or more cooling passages and digitally dividing the model into a plurality of sections. The plurality of sections defines one or more core sections and at least two shell sections. Each of the plurality of sections is next translated into a master tool. One or more precision metal inserts is disposed into one or more of the plurality of sections to define the geometry of the component including the interior passageway, the one or more cooling passages, the one or more surface grooves and one or more alignment features. Next, a flexible mold is cast from each master tool. The respective flexible molds are assembled to define a cavity therebetween. A ceramic core is cast from a respective flexible mold and a ceramic shell in at least two sections is cast from a respective flexible mold. A ceramic casting vessel is formed by assembling the ceramic core within the ceramic shell sections utilizing the one or more alignment features. A metal is then cast into the ceramic casting vessel. Subsequent removal of the ceramic casting vessel reveals a substrate of the component having the interior passageway, the one or more cooling passages in fluidic communication with the interior passageway and one or more surface grooves in fluidic communication with the one or more cooling passages. Finally, a coating is disposed over at least a portion of a surface of the substrate, wherein the one or more surface grooves and the coating define the one or more surface cooling channels for cooling the component.

[0012] These and additional features provided by the embodiments discussed herein will be more fully understood in view of the following detailed description, in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The embodiments set forth in the drawings are illustrative and exemplary in nature and not intended to limit the embodiments defined by the claims. The following detailed description of the illustrative embodiments can be understood when read in conjunction with the following drawings, where like structure is indicated with

like reference numerals and in which:

FIG. 1 is a schematic illustration of a gas turbine system including a component with surface cooling channels according to one or more embodiments shown or described herein;

FIG. 2 is a schematic cross-section of an exemplary airfoil configuration including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 3 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 4 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 5 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 6 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 7 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 8 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 9 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 10 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 11 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 12 is a cross-section of a step in a method of

making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 13 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 14 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein;

FIG. 15 is a cross-section of a step in a method of making a component including surface cooling channels according to one or more embodiments shown or described herein; and

FIG. 16 is a flow chart depicting one implementation of a method of making a component including surface cooling channels according to one or more embodiments shown or described herein.

DETAILED DESCRIPTION

[0014] One or more specific embodiments of the present disclosure will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0015] When introducing elements of various embodiments of the present disclosure, the components "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0016] Disclosed is a method of manufacturing surface cooling channels in a high-performance product, such an airfoil, made from metals, ceramics, polymers and/or composite material systems. The method enables the manufacture of an airfoil design with improved cooling characteristics that eliminates the need for the post-casting machining of the surface cooling channels. In an embodiment, coolant exit features may be placed in the applied coating after deposition of the coating, or the surface

cooling channels may be oriented to exit off the edges of the part.

[0017] The method of manufacture utilizes a novel molding or casting process based on the use of lithography and lithographic machining techniques to create a three-dimensional model of the finished airfoil. The method will be described in more detail herein.

[0018] FIG. 1 is a schematic diagram of a gas turbine system 10. The system 10 may include one or more compressors 12, combustors 14, turbines 16, and fuel nozzles 20. The compressor 12 and turbine 16 may be coupled by one or more shaft 18. The shaft 18 may be a single shaft or multiple shaft segments coupled together to form shaft 18.

[0019] The gas turbine system 10 may include a number of hot gas path components. A hot gas path component is any component of the system 10 that is at least partially exposed to a high temperature flow of gas through the system 10. For example, bucket assemblies (also known as blades or blade assemblies), nozzle assemblies (also known as vanes or vane assemblies), shroud assemblies, transition pieces, retaining rings, and compressor exhaust components are all hot gas path components. However, it should be understood that the hot gas path component of the present disclosure is not limited to the above examples, but may be any component that is at least partially exposed to a high temperature flow of gas. Further, it should be understood that the hot gas path component of the present disclosure is not limited to components in gas turbine systems 10, but may be any piece of machinery or component thereof that may be exposed to high temperature flows.

[0020] When a hot gas path component is exposed to a hot gas flow, the hot gas path component is heated by the hot gas flow and may reach a temperature at which the hot gas path component fails. Thus, in order to allow system 10 to operate with hot gas flow at a high temperature, increasing the efficiency and performance of the system 10, a cooling system for the hot gas path component is required.

[0021] In general, the cooling system of the present disclosure includes a series of small cooling channels, or microchannels, formed in the surface of the hot gas path component. The hot gas path component may include one or more grooves and a coating to bridge there over the grooves, and form the micro-channels. A cooling fluid may be provided to the micro-channels from a plenum, and the cooling fluid may flow through the micro-channels, cooling the coating and the substrate.

[0022] Referring now to FIG. 2, illustrated is an example of a hot gas component 30 having an airfoil configuration. As indicated, the component 30 comprises a substrate 32 with an outer surface 34 and an inner surface 36. The inner surface 36 of the substrate 32 defines at least one hollow, interior space 38. In an alternate embodiment, in lieu of a hollow interior space, the hot gas component 30 may include a supply cavity. The outer surface 34 of the substrate 32 defines a number of sur-

face cooling channels 40. Each of the surface cooling channels 40 extends at least partially along the outer surface 34 of the substrate 32 and in fluidic communication via one or more cooling passages 41 with the at least one hollow, interior space 38. A coating 42 is disposed over at least a portion of the outer surface 34 of the substrate 32, and more particularly over one or more grooves 44 formed in the outer surface 34 of the substrate 32, that in combination with the coating 42 form the surface cooling channels 40. In an embodiment, the hot gas component 30 may include multiple coatings 42, and the surface cooling channels 40 may be formed in the substrate 32 or partially in the substrate 32 and the one or more of the coatings 42.

[0023] As described below, the method disclosed herein includes lithography and lithographic machining techniques to create a three-dimensional model of the finished component, and more particularly the airfoil, including a plurality of surface cooling channels. Initially, a digital model of a component, such as an airfoil, is formed using a computerized design system, the use of which is well known in the art. The digital model is thereafter divided into a plurality of parts for castings. The plurality of castings are ultimately assembled into a casting vessel into which an alloy is cast. Ultimate removal of the casting vessel reveals a coolable structure having an interior passageway and one or more cooling passages in fluidic communication with the interior passageway and one or more open surface cooling channels. The method results in a component that requires no post casting machining to form the open surface cooling channels.

[0024] As previously indicated, an exemplary embodiment fabricated according to the method disclosed herein is the fabrication of a gas turbine airfoil, including an interior hollow passageway in fluidic communication with a plurality of surface cooling channels.

[0025] Referring more particularly to FIGs. 3-16, disclosed are steps in a method of fabricating the component 30. More particularly, disclosed are steps in a method for manufacturing a ceramic core 52 and a ceramic shell 54 of a ceramic casting vessel 56 that will define therein an interior passageway, one or more cooling passages, and one or more surface cooling channels of the component 30.

[0026] As indicated, the method provides for forming (as best illustrated in FIG. 2) the one or more surface channels, or grooves, 44 in the outer surface 34 of the hot gas component 30 in fluidic communication with the interior passageway 38. For the illustrated examples, multiple grooves 44 are formed in the outer surface 34. Each of the grooves 44 extends at least partially along the surface 34 of the component 30. In an embodiment, as shown, for example, in FIG. 3, initially a model 50 is provided of a desired ceramic casting vessel 56 defining the component 30 and including a plurality of inserts (described presently) to define the interior passageway 38 (FIG. 2) the one or more cooling passages 41 (FIG. 2) and the one or more grooves 44 (FIG. 2). The model is

digitally divided, as illustrated in FIG. 4, into a plurality of sections. More specifically, the model is digitally divided to define one or more core sections, of which a single core section 60 is illustrated, and at least two shell sections 62 and 64. It is noted that in the illustrated embodiment, core section 60, although illustrated as defined by a single section, may be too complex to form as a single section, and alternatively formed as a plurality of core sections. In an embodiment, dividing each of the core and shell into more than one section may ease the fabrication and allow for more precision details to be included.

[0027] Referring now to FIG. 5, next each of the plurality of sections, and more specifically the core section 60 and the plurality of shell sections 62 and 64 is translated into a master tool 66. Each of the master tools 66 is produced from the digital model 50 using well known machining processes to translate each section 60, 62, 64 to a respective master tool 66. At least one of the plurality of sections 60, 62 and 64 includes a plurality of precision metal inserts 70 to define the geometry of the component 30 including the one or more cooling passages 41 and the one or more surface grooves 44. Keeping in mind the three-dimensionality of such parts rather than just the two-dimensional cross sections shown in the figures, in an embodiment the metal inserts 70 may be formed of multiple layers themselves, such as etched copper sheets that are then stacked or locked into position. In addition, one or more precision metal inserts 70 may be included to define one or more alignment features 72. More specifically, as illustrated in FIG. 5, the core section 60 is translated into two cooperating master tools 67 and 69 that will ultimately form the ceramic core 52 of the ceramic casting vessel 56. Each of the master tools 66 is formed of any soft stable metal or metal alloy capable of being machined. In a preferred embodiment, the master tools 66 are formed of an aluminum material due to the advantages of cost and machining ease. Each of the master tools 66 and more particularly master tools 67 and 69, incorporate a machined surface 68, the precision metal inserts 70 and the alignment features 72 and reflects the intended shape of the component to be cast. In a preferred embodiment, the precision metal inserts 70 are formed of etched copper and are reflective of the geometry of the final one or more cooling passages 41 (FIG. 2) and the one or more surface grooves 44. Copper is the preferred material for the precision metal inserts 70 in that it is easily worked by etching or lithographic techniques, but any metal or alloy that is amenable to these techniques will work. As shown, for example, in FIG. 3, a final geometry of each of the grooves 44 has a base 46 and a top 48, where the base 46 is wider than the top 48, such that each of the grooves 44 comprises a re-entrant shaped groove 44. As indicated, for example, in FIG. 3, the method further includes forming the one or more cooling passages 56 coupled to the base 46 of a respective one of the grooves 44, to provide fluid communication between the grooves 44 and the one hollow

interior space(s) 38. The one or more cooling passages 56 are typically circular or oval in cross-section. The one or more cooling passages 56 may be normal to the base 46 of the respective grooves 44 (as shown in FIG. 3) or, more generally, may be formed at angles in a range of 20-90 degrees relative to the base 46 of the groove 44. Although the grooves 44 are described herein as re-entrant type grooves, fabrication of the grooves 44 as open format grooves is anticipated herein. The resultant overall surface geometry 74 of the master tool 66 is a combination of the machined surface 68 and the precision metal inserts 70 and indicative of the final shape of the ceramic core 52.

[0028] Referring now to FIG. 6, a plurality of flexible molds 80 are next cast from the master tools 66, and more particularly master tools 67 and 69. The flexible molds 80 will enable replication of the resultant surface geometry 74 of each of the master tools 66, and more particularly, the machined surface 68 and the precision metal inserts 70 of each of the master tools 67 and 69.

[0029] As best illustrated in FIG. 7, subsequent to curing, the master tools 67 and 69 are removed to reveal the flexible molds 80. The flexible molds 80 are positioned and aligned relative to one another to define therebetween a cavity 82. The cavity 82 is indicative of the shape of the ceramic core 52. In an embodiment, alignment inserts 84 are utilized in the formed alignment features 72 to aid in proper alignment of each half of the flexible molds 80 relative to one another.

[0030] Referring now to FIG. 8, subsequent to alignment of the two halves of the flexible molds 80, the cavity 82 is filled with a ceramic casting material 86. After curing, the flexible molds 80 are removed to reveal the ceramic core 52 including precision features that will form the one or more cooling passages 41 and one or more surface grooves 44, that will ultimately form the one or more surface cooling channels 40.

[0031] In addition to fabrication of the ceramic core 52, the ceramic casting vessel 56 further includes the ceramic shell 54. Accordingly, the ceramic shell 54 is next cast in at least two sections 62 and 64 which are then joined together and in combination with the ceramic core 52 enable fabrication of the component 30 including one or more surface grooves 44. As previously detailed, in a preferred embodiment of fabrication an airfoil, such as airfoil 30 of FIG. 2, the shell sections 62 and 64 are fabricated based on a digital model 50 of the ceramic shell 54 (FIGs. 3 and 5). In a preferred embodiment the digital model 50, and more particularly the ceramic casting vessel 56, is divided into a suction side and a pressure side. It is acknowledged that alternative locations for the split of the ceramic casting vessel 56 are anticipated herein, and dependent upon design parameters including shape and ease in fabrication in which some parts may require more than two shell sections.

[0032] Referring now to FIGs. 9 and 11, a master tool is fabricated for each of the shell sections 62 and 64 that comprise the ceramic shell 54 of the ceramic casting ves-

sel 56. More particularly, as illustrated, a first master tool 90 and second master tool 92 are fabricated for each shell section 62 and 64 in the same general manner as previously described for the core section 60. FIG. 9 illustrates the first master tool 90 of an exterior side 94 of shell section 62 being fabricated for subsequent casting of a flexible mold of the exterior side 94. FIG. 11 illustrates the second master tool 92 of an interior side 96 of shell section 62 being fabricated for subsequent casting of a flexible mold of the interior side 96. Although not illustrated, additional master tools are fabricated in the same manner for shell section 64 depicting both an interior side and an exterior side of the shell section 64. In an embodiment, the master tools 90 and 92 are formed of a soft metal material, or metal alloy, such as aluminum. As previously detailed, in an instance where precision tooling is required, a precision metal insert (not shown), similar to the precision metal inserts 70 of FIGs. 3-8, may be inserted into the master tools 90 and 92. In addition, in an embodiment cooperating alignment features 98 may be included in each master tool 90 and 92 to facilitate alignment of the master tools 90 and 92 during a subsequent flexible mold fabrication step.

[0033] A flexible mold is next fabricated for each master tool 90 and 92. More specifically, as illustrated in FIGs. 10 and 12, a flexible mold 100 is formed from the master tool 90, and a flexible mold 102 is formed from the master tool 92. The flexible molds 100 and 102 are formed in a manner generally described above with respect to the flexible mold 80 of the core section 60. In addition, additional flexible molds are fabricated in the same manner for shell section 64 depicting both an interior side and an exterior side of the shell section 64.

[0034] Next, as best illustrated in FIG. 13, the flexible molds 100 and 102 fabricated for the shell section 62 are positioned and aligned to define therebetween a cavity 82. In the illustrated embodiment, the cavity 104 is indicative of a portion of the shape of the final ceramic shell 54. Alignment inserts 106 may be utilized in the formed alignment features 98 to aid in proper alignment of each half of the flexible molds 100 and 102 relative to one another. Subsequent to alignment of the two halves of the flexible molds 100 and 102, the cavity 104 is filled with a ceramic casting material 108. After curing the flexible molds 100 and 102 are removed to reveal a portion of the ceramic casting vessel 56 and more particularly, one half of the ceramic shell 54. The process is repeated to fabricate the remaining one-half of the ceramic shell 54 of the ceramic casting vessel 56.

[0035] Referring now to FIG. 14, the ceramic casting vessel 56 is next formed by assembling the ceramic core 52 within the two ceramic shells 54 and thereby defining a complete mold of the component 30. The ceramic casting vessel 56 has defined therein a plurality of cavities 112. In an embodiment, locating features may be present in the at least two shell sections 62 and 64, and therefore in the resultant two ceramic shells 54, that line up with and insert with a top opening location in the one or more

core sections 60, and thus the resultant ceramic core 52. These locating features allow for "locking" in both the cores and shells, and therefore the surface channels to remain open, and keep the molten metal from bridging a web between the ceramic core 52 and the ceramic shells 54.

[0036] The ceramic casting vessel 56 subsequently receives a molten metal 110 into the ceramic casting vessel 56, and more particularly into the cavities 112 defined therein, using well known processes known in the art, to form the cast gas turbine blade 30 including a plurality of surface grooves 44. In a preferred embodiment, the molten metal 110, as discussed in US Patent No. 5,626,462, Melvin R. Jackson et al., "Double-wall airfoil," which is incorporated herein in its entirety, may include any suitable metal material. Depending on the intended application for component 30, this could include Ni-base, Co-base and Fe-base superalloys. The Ni-base superalloys may be those containing both γ and γ' phases, particularly those Ni-base superalloys containing both γ and γ' phases wherein the γ' phase occupies at least 40% by volume of the superalloy. Such alloys are known to be advantageous because of a combination of desirable properties including high temperature strength and high temperature creep resistance. The metal material 110 may also comprise a NiAl intermetallic alloy, as these alloys are also known to possess a combination of superior properties including high-temperature strength and high temperature creep resistance that are advantageous for use in turbine engine applications used for aircraft. In the case of Nb-base alloys, coated Nb-base alloys having superior oxidation resistance will be preferred, particularly those alloys comprising Nb-(27-40)Ti-(4.5-10.5)Al-(4.5-7.9)Cr-(1.5-5.5)Hf-(0-6)V, where the composition ranges are in atom per cent. The metal material may also comprise a Nb-base alloy that contains at least one secondary phase, such as a Nb-containing intermetallic compound comprising a silicide, carbide or boride. Such alloys are composites of a ductile phase (i.e., the Nb-base alloy) and a strengthening phase (i.e., a Nb-containing intermetallic compound). For other arrangements, the metal material comprises a molybdenum based alloy, such as alloys based on molybdenum (solid solution) with Mo_5SiB_2 and/or Mo_3Si second phases. For other configurations, the metal material comprises a ceramic matrix composite (CMC), such as a silicon carbide (SiC) matrix reinforced with SiC fibers. For other configurations the metal material comprises a TiAl-based intermetallic compound.

[0037] The ceramic casting vessel 56 is next removed to reveal the component 30 having the interior passageway 38, the one or more cooling passages 41 in fluidic communication with the interior passageway 38 and one or more surface grooves 44 in fluidic communication with the one or more cooling passages 41, a portion of which is illustrated in FIG. 15. As indicated, for example, in FIG. 15, the method further includes disposing a coating 42 over at least a portion of the surface 34 of the substrate

32 of the component 30. More particularly, in an embodiment the coating 42 is deposited over at least a portion of the surface 34 of the substrate 32 directly over open ones of the one or more grooves 44. As used here, "open" means that the grooves 44 are empty, i.e. they are not filled with a sacrificial filler. As shown in FIG. 15, for example, the grooves 44 and the coating 42 define a number of re-entrant shaped channels 40 for cooling the component 30. The substrate 32 and coating 42 may further define a plurality of exit film holes (not shown). Example coatings 42 are provided in US Patent No. 5,640,767 and US Patent No. 5,626,462, which are incorporated by reference herein in their entirety. As discussed in US Patent No. 5,626,426, the coatings 42 are bonded to portions of the surface 34 of the substrate 32. **[0038]** Beneficially, by forming re-entrant grooves 44, it is not necessary to use a sacrificial filler (not shown) to apply coating 42 to the substrate 32. This eliminates the need for a filling process and for the more difficult removal process. By forming reentrant shaped grooves with narrow openings 48 (tops), for example with openings 48 in the range of about 10-12 mils wide, the openings 48 can be bridged by the coating 42 without the use of a sacrificial filler, thereby eliminating additional processing steps (filling and leaching) beyond the eliminated post-machining step previously described, for conventional channel forming techniques. For the example configuration illustrated in FIG. 15, the coating 42 completely bridges the respective grooves 44, such that the coating 42 seals the respective surface cooling channels 40. In addition, in an embodiment, at least one coolant exit 45 may be defined through the coating 42.

[0039] Referring now to FIG. 16, illustrated is a flow chart depicting one implementation of a method 150 of making a component 30 including surface cooling channels 40 according to one or more embodiments shown or described herein. The method 150 includes casting the component 30 to ultimately include one or more surface cooling channels 40 by initially providing a model of a desired ceramic casting vessel defining the component 30, in a step 152. The model including an interior passageway, one or more cooling passages in fluidic communication with the interior passageway and one or more surface grooves in fluidic communication with the one or more cooling passages. Next, in a step 154, the model is digitally dividing into a plurality of sections, including a core section and a plurality of shell sections. Each of the plurality of sections is translated into a metal master tool, at step 156. The plurality of sections may include a plurality of precision metal inserts to define the geometry of the component including the interior passageway, the one or more cooling passages, the one or more surface grooves and one or more alignment features. The master tools are next aligned to cast a flexible mold from each metal master tool, in a step 158. Subsequent to curing of the flexible molds, the master tools are removed to reveal the flexible molds that are subsequently aligned and utilized to cast a ceramic core, at step 160 and a

ceramic shell, at step 162, from respective flexible molds. The ceramic casting vessel is next assembled, at step 164, by assembling the ceramic core within the ceramic shell sections, wherein the assembling may include utilizing the one or more alignment features. A metal material is subsequently cast, at step 166, into the ceramic casting vessel. After cooling, the ceramic casting vessel is removed, at step 168, to reveal the component having the interior passageway, the one or more cooling passages in fluidic communication with the interior passageway and one or more surface grooves in fluidic communication with the one or more cooling passages.

[0040] While the disclosed method has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the disclosed method is not limited to such disclosed embodiments. Rather, the method can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the disclosure. Additionally, while various embodiments of the method have been described, it is to be understood that aspects of the method may include only some of the described embodiments. Accordingly, the disclosed method is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

Claims

1. A method of casting a component (30) including one or more surface cooling channels (40), the method comprising:

casting (160) a ceramic core (52) from a flexible mold (80) of one or more core sections (60);
 casting (162) a ceramic shell (54) in at least two sections into respective flexible molds (100, 102) of at least two shell sections (62, 64);
 forming (164) a ceramic casting vessel (56) by assembling the ceramic core (52) within the ceramic shell sections (54);
 casting (166) a metal substrate material (110) into the ceramic casting vessel (56); and
 removing (168) the ceramic casting vessel (56) to reveal a substrate (32) of the component (30) having defined therein an interior passageway (38), one or more cooling passages (41) in fluidic communication with the interior passageway (38) and one or more surface grooves (44) in fluidic communication with the one or more cooling passages (41).

2. The method of Claim 1, further comprising:

providing (152) a model of a desired ceramic casting vessel (56) defining a geometry of the

component (30) and including the interior passageway (38), the one or more cooling passages (41) in fluidic communication with the interior passageway (38) and the one or more surface grooves (44) in fluidic communication with the one or more cooling passages (41);
 digitally dividing (154) the model into a plurality of sections defining the core section (52), the first shell section (62) and the second shell section (64);
 translating (156) each of the plurality of sections (52, 62, 64) into a master tool (66, 69, 90, 92) wherein the plurality of sections (52, 62, 64) include a one or more precision metal inserts (70) to define the geometry of the component (30) including the interior passageway (38), the one or more cooling passages (41) and the one or more surface grooves (44); and
 casting (158) the flexible molds (80, 100, 102) from each master tool (66, 69, 90, 92).

3. The method of Claim 1 or 2, further including disposing a coating (42) over at least a portion of a surface (34) of the substrate (32), wherein the one or more cooling passages (41), the one or more surface grooves (44) and the coating (42) define the one or more surface cooling channels (40) for cooling the component (30).

4. The method of Claim 3, further including defining at least one coolant exit (45) through the coating (42).

5. The method of any of Claims 1 to 4, wherein the one or more surface grooves (41) are re-entrant shaped grooves.

6. The method of any of Claims 2 to 5, wherein each of the master tools (67, 69, 90, 92) is formed of a metal material.

7. The method of any of Claims 2 to 6, wherein the plurality of sections (60, 62, 64) define one or more core sections (62) and at least two shell sections (62, 64).

8. The method of any of Claims 3 to 7, wherein the coating (42) completely bridges the respective one or more surface grooves (44) such that the coating (42) seals the respective one or more surface cooling channels (40).

9. The method of Claim 6, wherein the metal material is aluminum.

10. The method of Claim 6, wherein the precision inserts (70) are formed of a metal material.

11. The method of Claim 10, wherein the metal material

is etched copper.

12. The method of any of Claims 2 to 11, wherein the one or more precision metal inserts (70) further define one or more alignment features (72) and wherein forming the ceramic casting vessel (56) by assembling the ceramic core (52) within the ceramic shell sections (62,64) further includes utilizing the one or more alignment features (72).

5

10

15

20

25

30

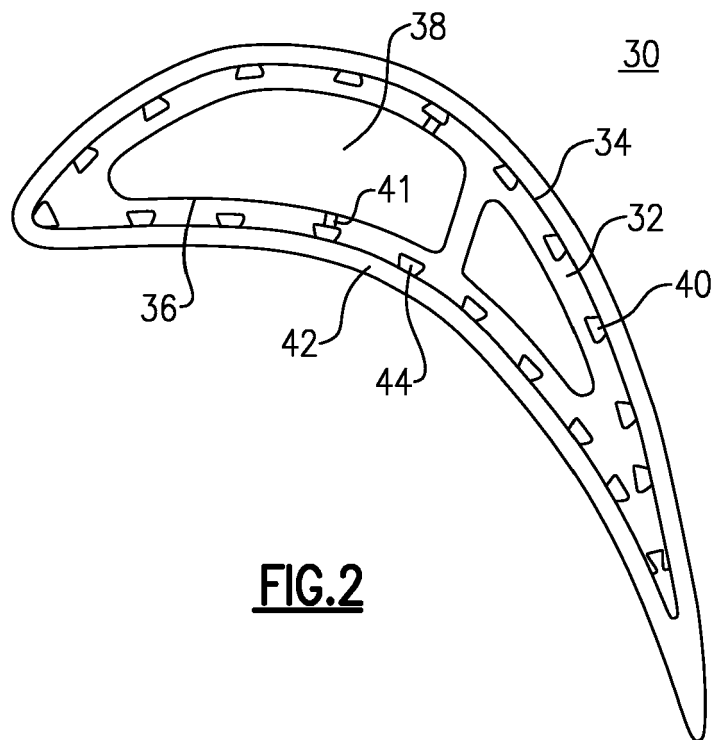
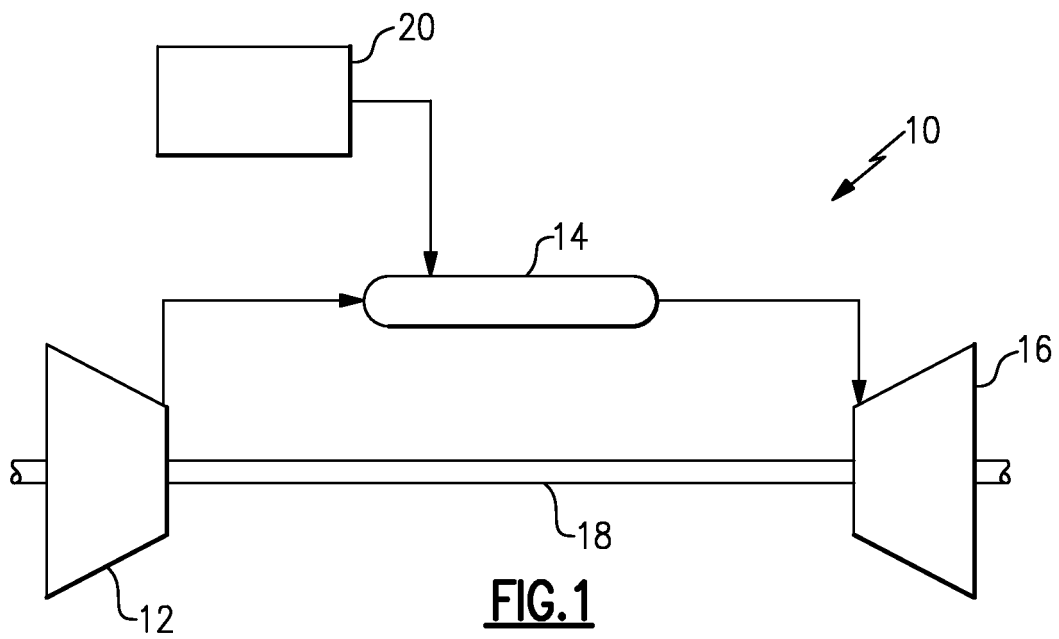
35

40

45

50

55



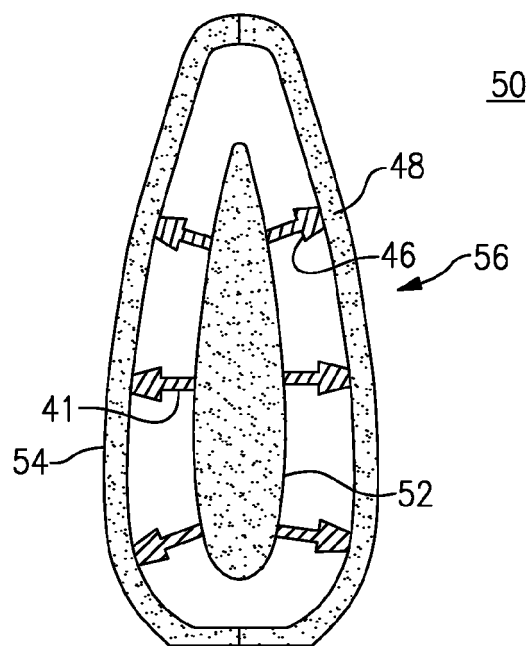


FIG. 3

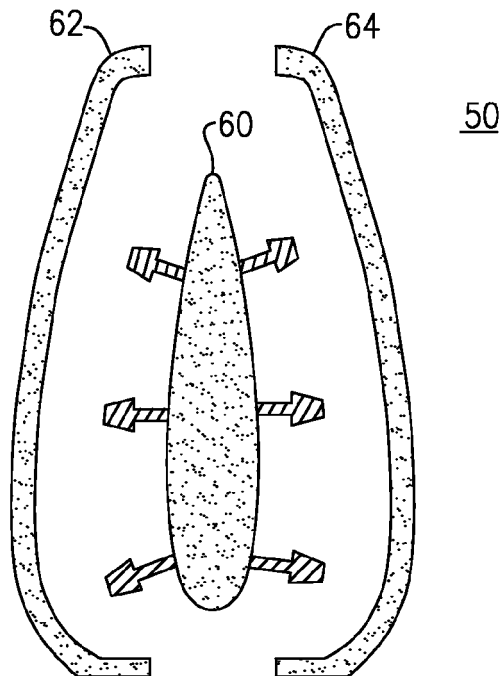
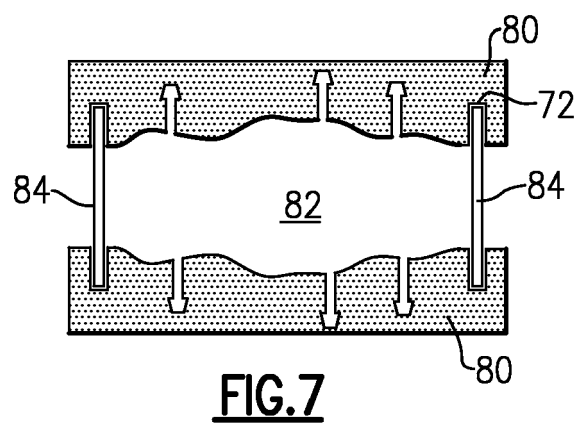
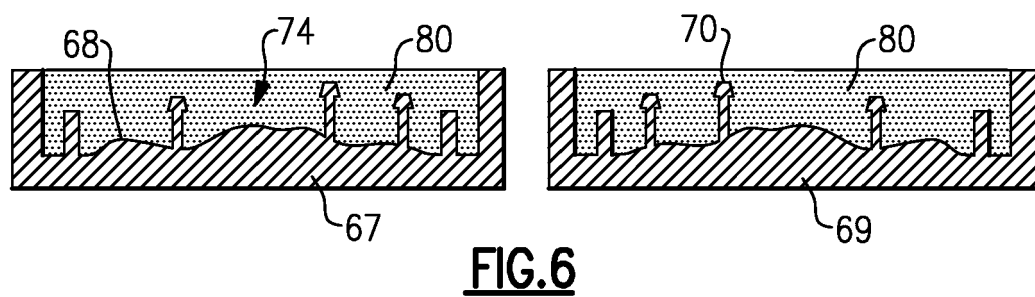
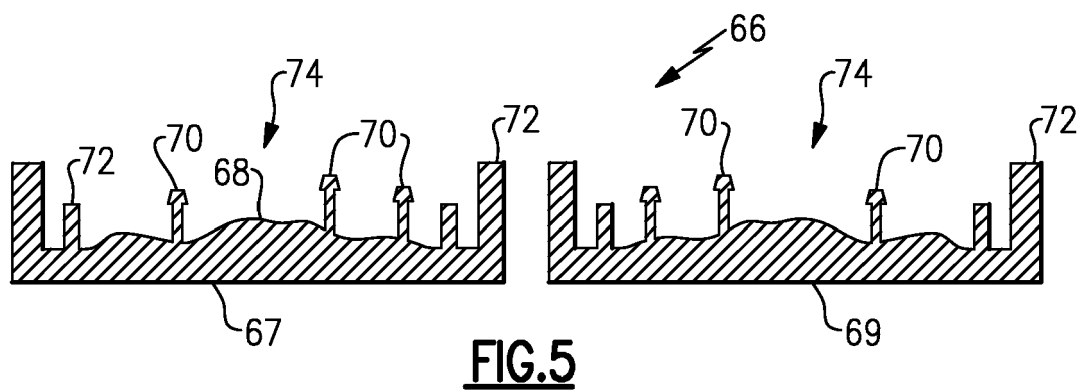


FIG. 4



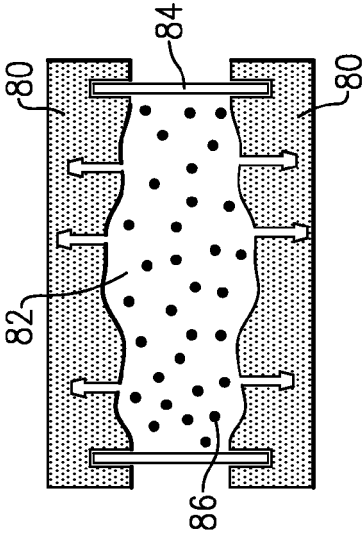


FIG. 8

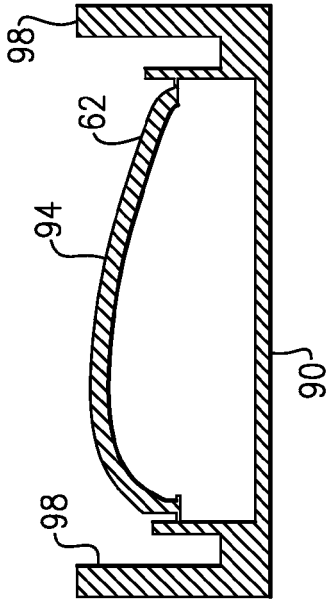


FIG. 9

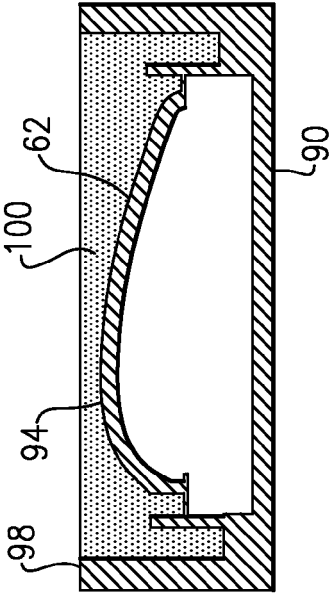


FIG. 10

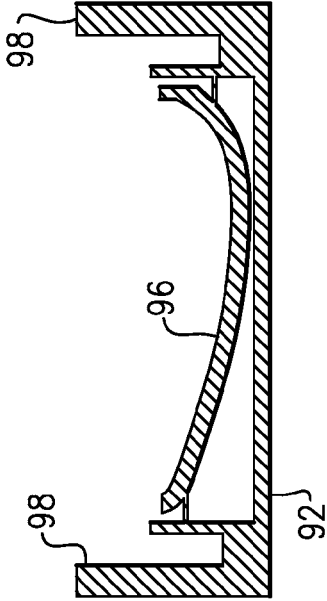


FIG. 11

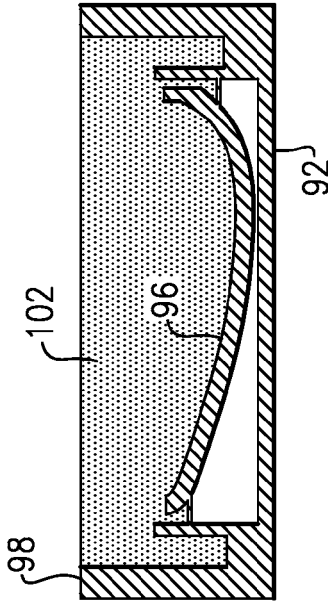


FIG. 12

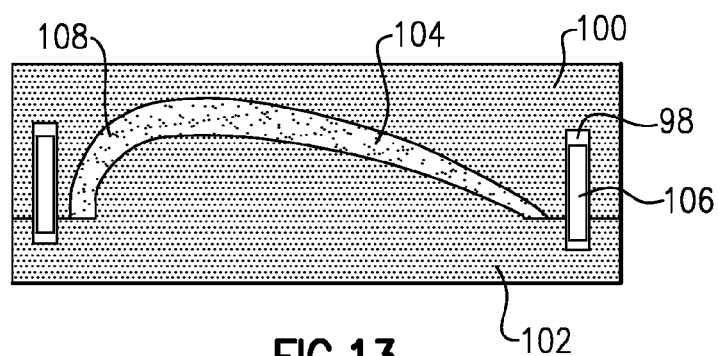


FIG. 13

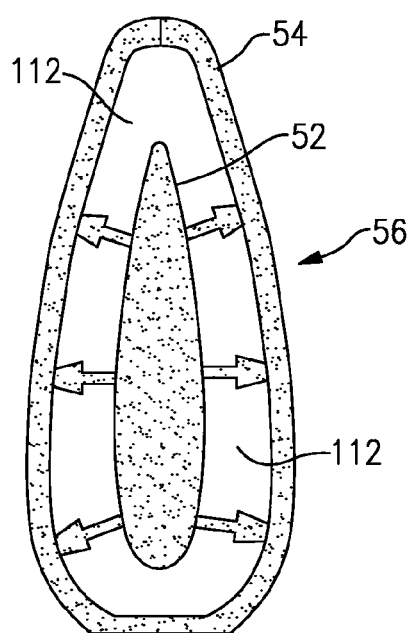


FIG. 14

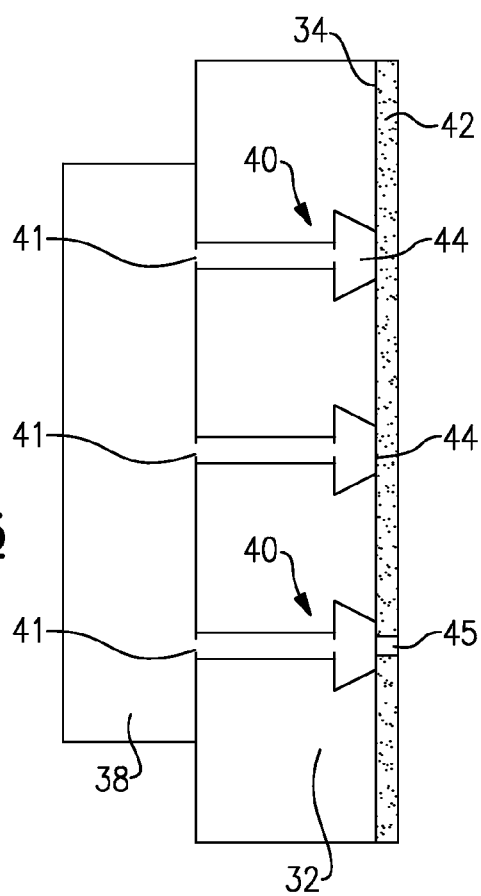
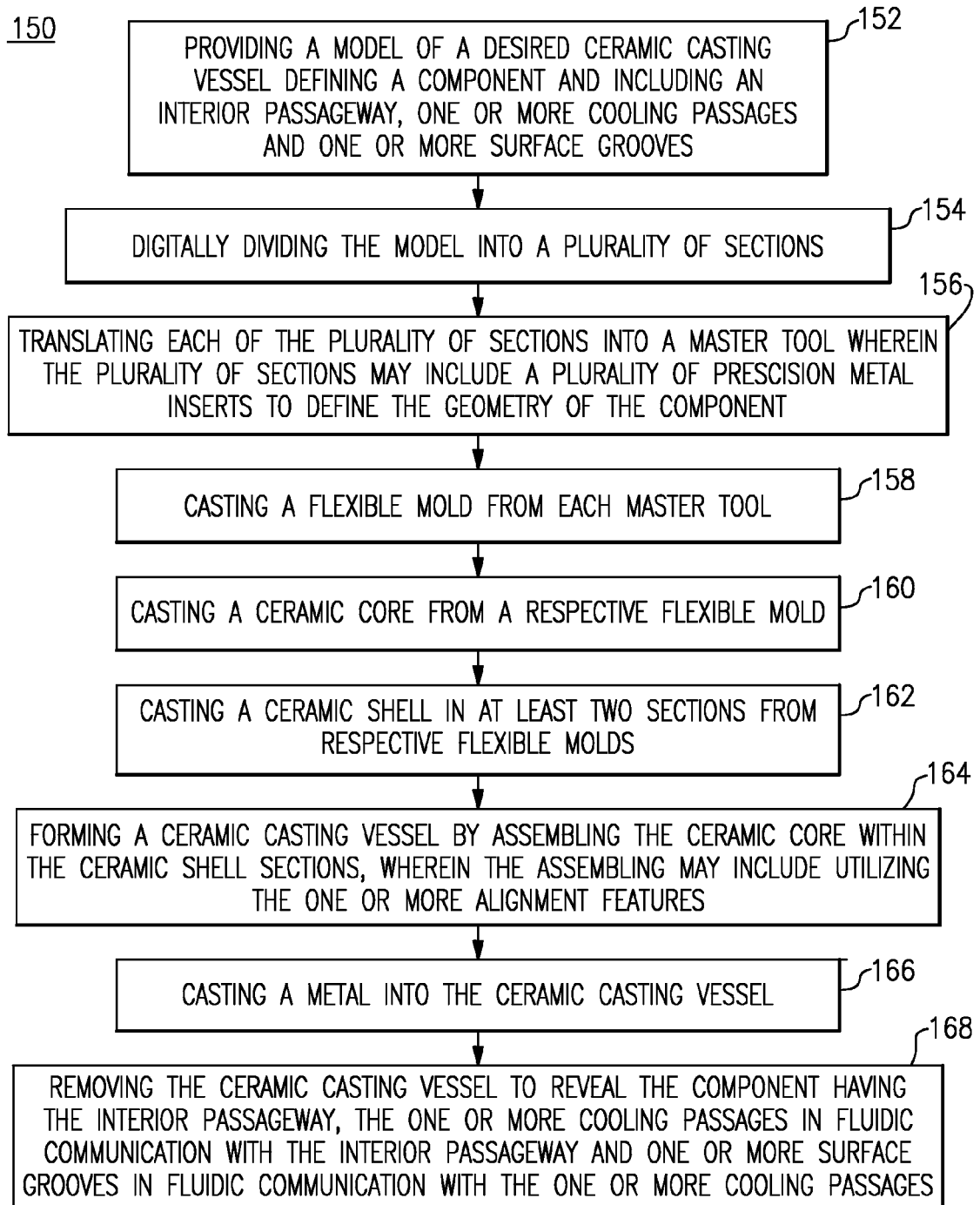


FIG. 15

**FIG.16**

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 5626462 A, Melvin R. Jackson [0036] [0037]
- US 5640767 A [0037]
- US 5626426 A [0037]