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(54) AIRFOIL FORMED WITH AN INTEGRAL CORE

(57) A method of forming an integral casting core (52) includes adding a disposable insert (50) to a core die (48) with the disposable insert (50) defining an inner wall in a two-circuit airfoil. A slurry is disposed into the core die (48) and fired to form an integral casting core (52). The disposable insert (50) is removed from the integral casting core (52).

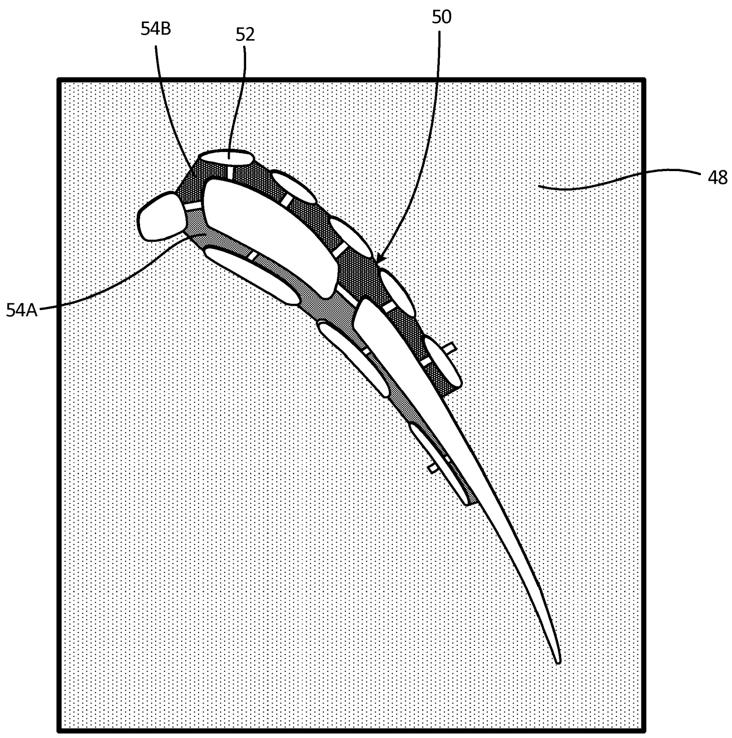


Fig. 3

EP 3 381 584 A1

Description

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] Reference is made to application Ser. No.____entitled "AIRFOIL FORMED WITH AN INTEGRAL CORE", which is filed on even date and are assigned to the same assignee as this application.

BACKGROUND

[0002] The present inventions is related to airfoils, and, more particularly, to the forming of airfoils.

[0003] The high temperatures of gases and components within gas turbine engines require advanced cooling solutions. In the "hot sections" of a gas turbine engine, the walls of some components can be exposed to gases having temperatures above the melting point of the material used to form the walls. As a result, the components can contain a number of cavities through which cooling air flows to reduce component temperature. However, forming an airfoil with cooling cavities can be difficult and expensive to manufacture.

SUMMARY

[0004] According to an embodiment, a method of forming an integral casting core includes adding a disposable insert to a core die with the disposable insert defining an inner wall in a two-circuit airfoil. A slurry is disposed into the core die and fired to form an integral casting core. The disposable insert is removed from the integral casting core.

[0005] From a first aspect, the invention provides a method of forming an integral casting core comprising: adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a two-circuit airfoil; disposing a first slurry into the core die; firing the slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and removing the disposable insert from the integral casting core.

[0006] Preferably the two-circuit airfoil comprises: a plurality of outer cavities; and a first inner cavity.

[0007] Still more preferably, the two-circuit airfoil comprises: an outer circuit that forms at least some of an exterior of the airfoil and defines an outer portion of the plurality of outer cavities; and an inner circuit that defines an inner portion of the plurality of outer cavities and surrounds the first inner cavity.

[0008] Still more preferably, the inner circuit completely defines the first inner cavity and /or the inner circuit comprises a divider that separates the first inner cavity from a second inner cavity that is completely defined by the inner circuit.

[0009] In any aspect of the invention, the step of removing the disposable insert preferably occurs during the firing of the first slurry.

[0010] In any aspect of the invention, the first slurry preferably comprises ceramic particles.

[0011] In any aspect of the invention, the method further comprises: disposing the integral casting core into an investment casting die; injecting a wax into the investment casting die to form a wax component; immersing the wax component into a second slurry to form an outer shell; firing the wax component with the outer shell in a second firing process to form a ceramic shell; removing the wax from the ceramic shell; disposing a molten metal into the ceramic shell; and removing the ceramic shell to yield a molded component.

[0012] From a further aspect, a method of forming an integral casting core is provided, comprising: adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a three-zone airfoil; disposing a first slurry into the core die; firing the first slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and removing the disposable insert from the integral casting core.

[0013] Preferably the three-zone airfoil comprises: a first zone that begins at a leading edge of the three-zone airfoil and includes a first cavity; a second zone that begins at a trailing edge of the three-zone airfoil and includes a second cavity; and a third zone positioned between the first and second zones, the third zone comprising: a third cavity positioned proximate a pressure side of the three-zone airfoil; a fourth cavity positioned proximate a suction side of the three-zone airfoil; and a fifth cavity positioned between the third and fourth cavities.

[0014] Preferably the second cavity extends into the third zone.

[0015] The method preferably further comprises: a sixth cavity in the third zone positioned between the second cavity and the pressure side; and a seventh cavity in the third zone positioned between the second cavity and the suction side.

[0016] Preferably the third zone further comprises: an eighth cavity positioned between the fifth cavity and the pressure side, adjacent the third cavity; and a ninth cavity positioned between the fifth cavity and the suction side, adjacent the fourth cavity.

[0017] In any aspect of the invention, the method may further comprise: disposing the integral casting core into an investment casting die; injecting a wax into the investment casting die to form a wax component; immersing the wax component into a second slurry to form an outer shell; firing the wax component with the outer shell in a second firing process to form a ceramic shell; removing the wax from the ceramic shell; disposing a molten metal into the ceramic shell; and removing the ceramic shell to yield a molded component.

[0018] In any aspect of the invention the step of removing the disposable insert preferably occurs during the firing of the first slurry.

[0019] In any aspect of the invention, the first slurry preferably comprises ceramic particles.

[0020] From a further aspect of the invention, a method of forming an integral casting core is provided comprising: adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a quadruple-wall airfoil; disposing a first slurry into the core die, wherein the first slurry comprises ceramic particles; firing the slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and removing the disposable insert from the integral casting core.

[0021] Preferably the quadruple-wall airfoil comprises: a pressure side wall; a first inner wall spaced apart from the pressure side wall; a second inner wall that is spaced apart from the first inner wall and is positioned opposite of the pressure side wall with respect to the first inner wall; and a suction side wall that is spaced apart from the second inner wall and is positioned opposite of the first inner wall with respect to the second inner wall.

[0022] Still more preferably, the quadruple-wall airfoil further comprises: a first cavity positioned between the pressure side wall and the first inner wall; a second cavity positioned between the first inner wall and the second inner wall; and a third cavity positioned between the second inner wall and the suction side wall.

[0023] Still more preferably, first and second inner walls terminate at a divider that is positioned proximate to the leading edge.

[0024] In any aspect of the invention, the step of removing the disposable insert preferably occurs during the firing of the first slurry.

[0025] In any aspect of the invention, the method preferably further comprises: disposing the integral casting core into an investment casting die; injecting a wax into the investment casting die to form a wax component; immersing the wax component into a second slurry to form an outer shell; firing the wax component with the outer shell in a second firing process to form a ceramic shell; removing the wax from the ceramic shell; disposing a molten metal into the ceramic shell; and removing the ceramic shell to yield a molded component.

[0026] From a further aspect, the invention provides a method of forming an airfoil with an integral casting core comprising: adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a two-circuit airfoil; disposing a first slurry into the core die; firing the slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; removing the disposable insert from the integral casting core; disposing the integral casting core into an investment casting die; injecting a wax into the investment casting die to form a wax component; immersing the wax component into a second slurry to form an outer shell; firing the wax component with the outer shell in a second firing process to form a ceramic shell; removing the wax from the ceramic shell; disposing a molten metal into the ceramic shell; and removing the ceramic shell to yield the airfoil.

[0027] Preferably the two-circuit airfoil comprises: a plurality of outer cavities; and a first inner cavity.

[0028] Still more preferably, the two-circuit airfoil comprises: an outer circuit that forms at least some of an exterior of the airfoil and defines an outer portion of the plurality of outer cavities; and an inner circuit that defines an inner portion of the plurality of outer cavities and surrounds the first inner cavity.

[0029] In any aspect of the invention, the inner circuit preferably completely defines the first inner cavity.

[0030] In any aspect of the invention, the inner circuit preferably comprises a divider that separates the first inner cavity from a second inner cavity that is completely defined by the inner circuit.

[0031] In any aspect of the invention, the step of removing the disposable insert preferably occurs during the firing of the first slurry.

[0032] In any aspect of the invention, the first slurry preferably comprises ceramic particles.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033]

FIG. 1 is a side view of a blade.

FIG. 2 is a cross section view of the blade of FIG. 1 taken along the line A-A.

FIG. 3 is a cross section view of a core die including a disposable insert and an integral casting core that corresponds to the location on the blade of FIG. 1 at line A-A.

FIG. 4 is a cross section view of the integral casting core of FIG. 3 positioned in an investment casting die.

FIG. 5 is a cross section view of a shell positioned in an airfoil die.

FIG. 6 is a flow diagram of a process of forming an airfoil.

DETAILED DESCRIPTION

[0034] Multiple wall components can offer improved cooling capabilities compared to simpler, single wall structures. Examples of components that can have multiple walls (e.g., dual walls) include, but are not limited to, blades, vanes, and blade outer air seals (BOAS). The features of a blade will be used to describe one example of a multi-wall component including a method of forming such a component. FIG. 1 is a side view of blade 10. Blade 10 includes root section 12, platform 14, airfoil 16 and tip section 18. Blade 10 extends from root section 12 to tip section 18 along a radial axis. Airfoil 16 extends radially from platform 14. Airfoil 16 includes pressure side wall 20 and suction side wall 22, which extend from leading edge 24 to trailing edge 26.

[0035] FIG. 2 is a cross section view of blade 10 of FIG. 1 taken along the line A-A and illustrates the multiple walls of airfoil 16. Pressure side wall 20 forms a first outer wall, and suction side wall 22 forms a second outer wall, the two walls meeting at leading edge 24 and trailing edge 26. Airfoil 16 also includes first divider 27, first inner wall 28, second divider 29, and second inner wall 30. First divider 27 extends between pressure side wall 20 and suction side wall 22, proximate leading edge 24, and second divider 29 extends between pressure side wall 20 and suction side wall 22, proximate the mid-chord of airfoil 16. First inner wall 28 and second inner wall 30 are spaced apart from one another and from walls 20 and 22, and each inner wall 28 and 30 extends from first divider 27, past second divider 29, towards trailing edge 26.

[0036] In the illustrated embodiment, pressure side wall 20 and suction side wall 22 form an outer circuit that forms some of the exterior of airfoil 16. Positioned inside of the outer circuit and outside of an inner circuit is a plurality of outer cavities 32. First divider 27, first inner wall 28, second divider 29, and second inner wall 30 form the inner circuit that is offset inward from the outer circuit. Some of outer cavities 32 are located between the inner circuit and the outer circuit, and others are positioned closer to trailing edge 26 than second divider 29. The outer portions of outer cavities 32 are defined by either pressure side wall 20 or suction side wall 22, and the inner portions of outer cavities 32 are defined by either first inner wall 28 or second inner wall 30, respectively. In addition to the dual-circuit conceptualization, such an arrangement can be thought of as a quadruple-wall configuration because in some areas of airfoil 16, four walls would be encountered when moving perpendicularly across airfoil 16 in the chordal direction.

[0037] Airfoil 16 further includes nose cavity 34 positioned proximate leading edge 24, wherein nose cavity 34 is defined by pressure side wall 20, suction side wall 22, and first divider 27. In addition, airfoil 16 includes inner cavities 36A and 36B. Inner cavity 36A is completely defined by the inner circuit, which is more specifically first divider 27, first inner wall 28, second divider 29, and second inner wall 30. Inner cavity 36B is defined by pressure side wall 20, suction side wall 22, and second divider 29. Such an arrangement can be conceptualized as a quadruple-wall configuration because in some areas of airfoil 16, four walls would be encountered when moving perpendicular to the chordal direction. Due to nose cavity 34 and inner cavities 36A and 36B, airfoil 16 can be thought of as a three-zone airfoil. First zone 38 extends from leading edge 24 to the upstream end of outer cavities 32 and includes nose cavity 34 (but none of outer cavities 32 or inner cavities 36A and 36B). Second zone 40 extends from the upstream end to the downstream end of outer cavities 32 and includes all of outer cavities 32, all of inner cavity 36A, and a portion of inner cavity 36B. Third zone 42 extends from the downstream end of outer cavities 32 to trailing edge 26 and includes the remainder of inner cavity 36B that is not in second zone 40.

[0038] Inner cavities 36A and 36B allow for cooling air (not shown) to be transported through airfoil 16 and distributed amongst outer cavities 32 via intermittent channels 44. Having cooling air flowing through outer cavities 32 cools pressure side wall 20 and suction side wall 22. In some embodiments, there are passages 46 which connect an outer cavity 32 to the environment that is exterior to airfoil 16. Cooling air flow through passages 46 can form a cooling film along the exterior of airfoil 16, further regulating the temperature of pressure side wall 20 and suction side wall 22. The configuration of airfoil 16 allows for better impingement cooling and more uniform internal air flow than traditionally configured cooled airfoils.

[0039] In alternate embodiments, airfoil 16 can have more or less outer cavities 32 than eight. Furthermore, outer cavities 32 can only be present proximate one of pressure side wall 20 or suction side wall 22. Such embodiments can be considered to have triple-wall configurations because in some areas, three walls would be encountered when moving perpendicularly across such airfoils in the chordal direction.

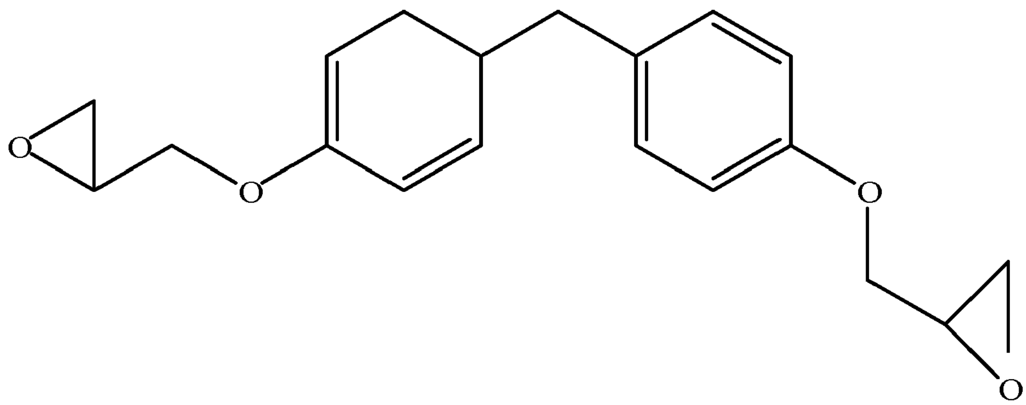
[0040] FIG. 3 is a cross section view of core die 48 including disposable insert 50 and integral casting core 52 that corresponds to the location on blade 10 of FIG. 1 at line A-A, and is used to form an airfoil with triple or quadruple wall construction, as previously described in FIG. 2. In order to use core die 48, disposable insert 50 has been added to core die 48. After this step, a slurry has been disposed into core die 48 to form a negative of the interior cavities and passages of blade 10 (shown in FIGS. 1 and 2). Core die 48 (including the slurry and disposable insert 50) has then been put through a process to solidify and/or cure the slurry to form integral casting core 52. Such a process can be, for example, firing core die 48 in a kiln.

[0041] In order to use integral casting core 52 in the next steps, disposable insert 50 is removed from integral casting core 52. The step of removal can occur during the solidification and/or curing process or afterwards. Removal of disposable insert 50 can occur using chemical, thermal, and/or mechanical methods to dissolve, degrade, divide, melt, burn, and/or otherwise destroy disposable insert 50. Such methods can include the application of acids, bases, abrasives, cutting tools, radiation, heat, and/or cold to disposable insert 50.

[0042] In the illustrated embodiment, disposable insert 50 comprises insert parts 54A and 54B. Insert parts 54A and 54B are in contact with one another and define what will become the inner sides of outer cavities 32, the downstream portion of nose cavity 34, inner cavity 36A, the upstream portion of inner cavity 36B, and channels 44. Correspondingly, core die 48 defines what will become the outer sides of outer cavities 32, the upstream portion of nose cavity 34, the downstream portion of inner cavity 36B, and passages 46 (all shown in FIG. 2). In alternate embodiments, disposable insert 50 can be comprised of more or less parts than two.

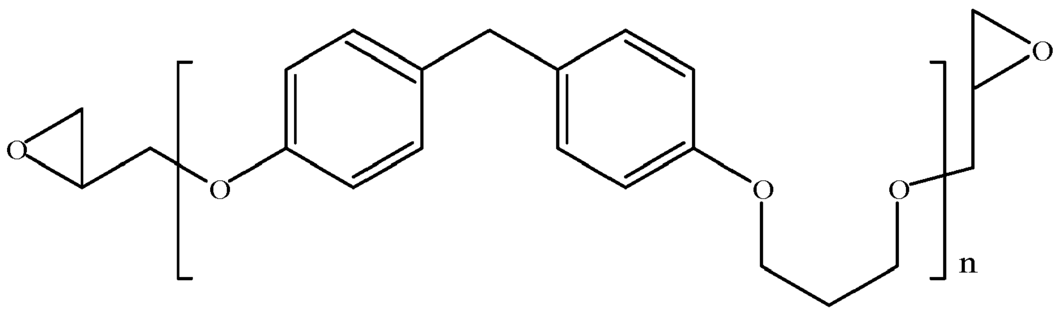
[0043] Core die 48 can be comprised of at least one of several suitable materials, for example, metal, crosslinkable polymers such as epoxy, silicone (e.g., polysiloxane, in particular polydimethylsiloxane), polyimides, epoxysilanes, phenolics, polyurethanes, polysilsesquioxanes, ceramic, organic matrix composites, metal matrix composites, and other hybrid materials. The silicone can be backed by (for example, adhered to) a metal or epoxy material to make a hybrid-material core die 48 such that the silicone is in contact with the slurry. In addition, the ceramic material can be in the form of a monolithic ceramic material or a ceramic matrix composite (CMC) material. Disposable insert 50 can be comprised of at least one of several suitable materials, for example, epoxy, silicone (e.g., polysiloxane, in particular polydimethylsiloxane), ceramic, organic matrix composites, metal matrix composites, and other hybrid materials. The silicone can be backed by (for example, adhered to) a metal or epoxy material to make a hybrid-material disposable insert 50 such that the silicone is in contact with the slurry. In addition, the ceramic material can be in the form of a monolithic ceramic material or a ceramic matrix composite (CMC) material. The slurry used to form integral casting core 52 can be comprised of a refractory metal core (RMC) material or a ceramic material suspended in a polymeric material, such as wax. At least some of the materials that can be used for core die 48 and/or integral casting core 52 are advantageous because they have a lower thermal conductivity than that of traditional metal materials.

[0044] Examples of epoxies that may be used in the core die are aromatic, aliphatic or cycloaliphatic epoxy resins. In an embodiment, a useful epoxy resin is the diglycidyl ether of bisphenol F, also known as EPON 862®, available from Hexion Inc. of Columbus, Ohio, and having the structure shown in Formula (1):



(1)

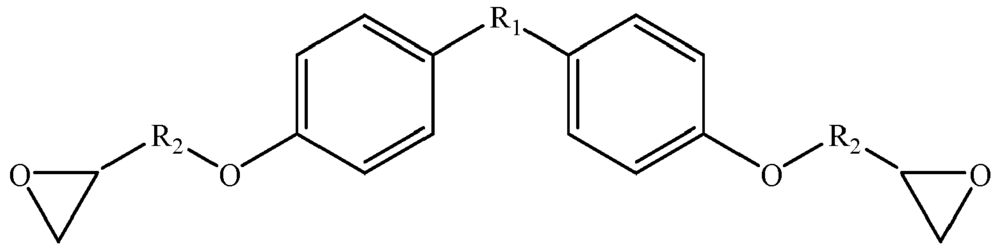
[0045] In another embodiment, the epoxy resin is a modified diglycidyl ether of bisphenol F also known as a modified EPON 862® and having the structure shown in Formula (2):



(2)

where n is the number of repeat units. The epoxy resin of the formula (1) is produced by polymerizing bisphenol F with the EPON 862®.

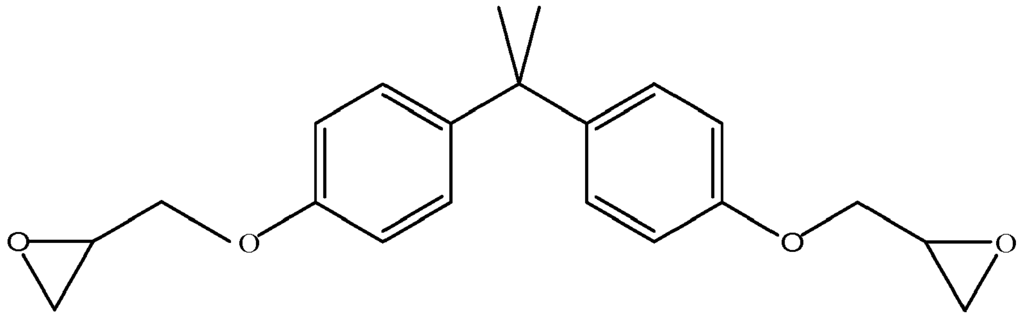
[0046] In an embodiment, the epoxy resin may have the structure shown in the Formula (3) below:



(3)

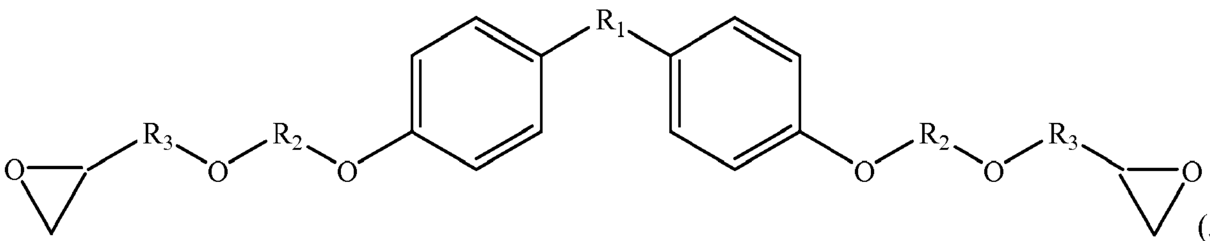
where R1 is a single bond, -O-, -S-, -C(O)-, or a C1-18 organic group. The C1-18 organic bridging group may be cyclic or acyclic, aromatic or non-aromatic, and can further comprise heteroatoms such as halogens, oxygen, nitrogen, sulfur, silicon, or phosphorous. The C1-18 organic group can be disposed such that the C6 arylene groups connected thereto are each connected to a common alkylidene carbon or to different carbons of the C1-18 organic bridging group. In the Formula (6), R2 is a C1 - 30 alkyl group, a C3-30 cycloalkyl, a C6-30 aryl, a C7-30 alkaryl, a C7-30 aralkyl, a C1-30 heteroalkyl, a C3-30 heterocycloalkyl, a C6-30 heteroaryl, a C7-30 heteroalkaryl, a C7-30 heteroaralkyl, a C2-10 fluoroalkyl group, or a combination thereof.

[0047] In yet another exemplary embodiment, the epoxy resin is the reaction product of 2-(chloromethyl)oxirane and 4-[2-(4-hydroxyphenyl)propan-2-yl]phenol also known as bisphenol A-epichlorohydrin based epoxy (also known as bisphenol A diglycidyl ether) of the Formula (4) below:



(4)

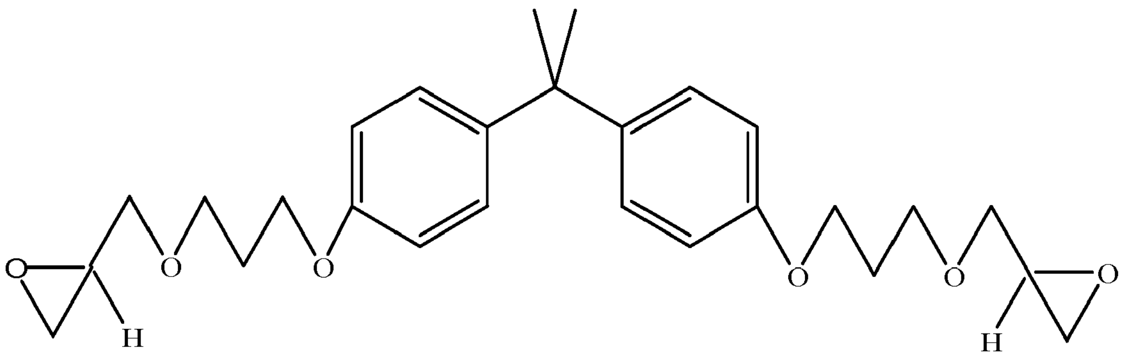
[0048] The epoxy resin of Formula (4) is commercially available as EPON 828®, available from Hexion Inc. of Columbus, Ohio. Other exemplary variations of Formula (3) that may be used are shown in the Formulas (5) and (6). In an embodiment, one variation of the Formula (6) that may be used is shown in the Formula (5) below.



(5),

(where R1 is detailed above in Formula (3), R2 and R3 may be the same or different and are independently a C1 - 30 alkyl group, a C3-30 cycloalkyl, a C6-30 aryl, a C7-30 alkaryl, a C7-30 aralkyl, a C1-30 heteroalkyl, a C3-30 heterocycloalkyl, a C6-30 heteroaryl, a C7-30 heteroalkaryl, a C7-30 heteroaralkyl, a C2-10 fluoroalkyl group, or a combination thereof.

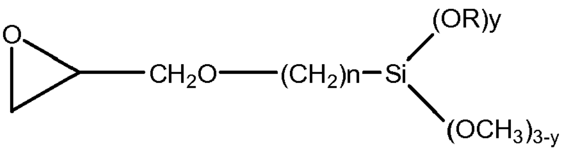
[0049] In an exemplary embodiment, an epoxy having the structure of Formula (6) may be used in the coating.



(6).

[0050] Examples of suitable epoxies are diglycidyl ether of bisphenol A, diomethane diglycidyl ether, 2,2-bis(4-glycidyloxyphenyl)propane, 2,2'-((1-methylethylidene)bis(4,1-phenyleneoxymethylene))bisoxirane, 2,2-bis(4-(2,3-epoxypropyloxy)phenyl)propane, 2,2-bis(4-hydroxyphenyl)propane, diglycidyl ether, 2,2-bis(p-glycidyloxyphenyl)propane, 4,4'-bis(2,3-epoxypropoxy)diphenyldimethylmethane, 4,4'-dihydroxydiphenyldimethylmethane diglycidyl ether, 4,4'-isopropylidenebis(1-(2,3-epoxypropoxy)benzene), 4,4'-isopropylidenediphenol diglycidyl ether, bis(4-glycidyloxyphenyl)dimethylmethane, bis(4-hydroxyphenyl)dimethylmethane diglycidyl ether, diglycidyl ether of bisphenol F, 2-(butoxymethyl)oxirane, the reaction product of 2-(chloromethyl)oxirane and 4-[2-(4-hydroxyphenyl)propan-2-yl]phenol also known as bisphenol A-epichlorohydrin based epoxy, modified bisphenol A - epichlorohydrin based epoxy, diglycidyl 1,2-cyclohexanedicarboxylate, 1,4-cyclohexanedimethanol diglycidyl ether, a mixture of cis and trans 1,4-cyclohexanedimethanol diglycidyl ether, neopentyl glycol diglycidyl ether, resorcinol diglycidyl ether, 4,4'-methylenebis(N,N-diglycidylaniline), 3,4-epoxycyclohexylmethyl 3,4-epoxycyclohexanecarboxylate, 3,4-epoxy-1-cyclohexanecarboxylic acid, 3,4-epoxycyclohexan-1-yl)methyl ester, tert-butyl glycidyl ether, 2-Ethylhexyl glycidyl ether, epoxypropoxypropyl terminated polydimethylsiloxanes, neopentyl glycol diglycidyl ether, 1,4-cyclohexanedimethanol diglycidyl ether, 1,3-bis[2-(3,4-epoxycyclohexyl)ethyl]tetramethyldisiloxane, trimethylolpropane triglycidyl ether, diglycidyl 1,2-cyclohexanedicarboxylate, or the like, or a combination thereof.

[0051] In an embodiment, one of the foregoing epoxies may be combined with the precursor to a metal oxide and an epoxysilane (shown in the formula (7) below) in order to produce the nanoparticle coating composition on the substrate.

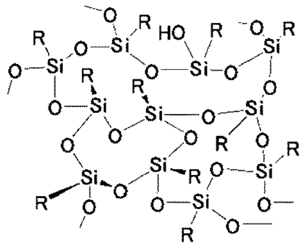


(7)

[0052] In yet another embodiment, the nanoparticles may be modified by using an oligomer that is endcapped with an alkoxysilane.

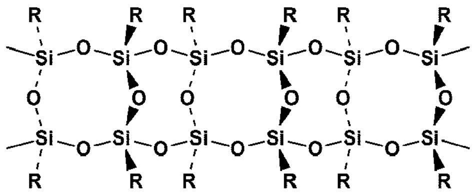
[0053] Silsesquioxanes have the structure (RSiO1.5)n wherein R represents one or more types of substituents, typically organic in nature. An alternate designation is "T-resin," indicating that there are three (tri-substituted) oxygen atoms substituting the silicon. These molecules have rigid, thermally stable silicon-oxygen frameworks whose structures and characteristics are intermediate between those of silica glass (SiO2)n and silicone polymer (R2SiO)n. The silsesquioxane moieties in the coating composition may be selected from among various structural types: polyhedral cage, ladder, random, or a mixture thereof, as shown in formulas 8 - 10 below.

[0054] Formula (8) shows a random silsesquioxane moiety



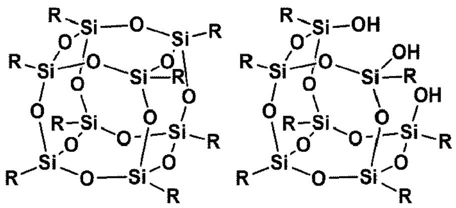
(8),

while Formula (9) depicts ladder silsesquioxanes:



(9)

and Formula (10) depicts complete and incomplete (partial) polyhedral cage silsesquioxanes.



(10).

Polysilsesquioxanes with epoxy functionalities may also be used if desired.

[0055] FIG. 4 is a cross section view of integral casting core 52 (without disposable insert 50) of FIG. 3 positioned in investment casting die 56. A fluid material, such as wax has been disposed in investment casting die 56 and solidified and/or cured to create investment airfoil 58. Investment airfoil 58 is substantially the same as blade 10 (shown in FIG. 1), except for the material and presence of integral casting core 52.

[0056] Investment airfoil 58 is then coated with a ceramic slurry to form shell 60. FIG. 5 is a cross section view of shell 60 (including integral casting core 52) positioned in airfoil die 62. Investment airfoil 58 is then removed from shell 60, and molten metal is then disposed in airfoil die 62. Alternatively, the molten metal can be used to melt or burn investment airfoil 58 as the molten metal is disposed in airfoil die 62. Following the cooling and solidification of the molten metal, shell 60 is broken and integral casting core 52 is removed via a chemical and/or mechanical process, leaving only blade 10 (shown in FIG. 1).

[0057] FIG. 6 is a flow diagram of a process of forming an airfoil. At step 100, disposable insert 50 is added to core die 48. At step 102, core die 48 is closed and a first ceramic slurry is disposed into core die 48. At step 104, the first ceramic slurry is fired to form integral casting core 52. At step 106, disposable insert 50 is removed from integral casting core 52.

[0058] At step 108, integral casting core 52 is disposed into investment casting die 56. At step 110, wax is injected into investment casting die 56 to form a wax airfoil. At step 112, the wax airfoil is immersed into a second slurry (that may be the same or a different material from the first slurry) and then dried to form an outer shell. At step 114, the wax airfoil with the outer shell is fired to form a ceramic shell. At step 116, the wax airfoil is removed from the ceramic shell (although this step can occur simultaneously with step 114 or 118, if desired).

[0059] At step 118, a molten metal, ceramic, or polymer material is disposed into the ceramic shell to form at least airfoil 16, if not the entirety of blade 10. At step 120, airfoil 16 or blade 10 is removed from the ceramic shell. At step 122, integral casting core 52 is removed from airfoil 16 or blade 10.

DISCUSSION OF POSSIBLE EMBODIMENTS

[0060] The following are non-exclusive descriptions of possible embodiments of the present invention.

[0061] A method of forming an integral casting core according to an exemplary embodiment of this disclosure, among other possible things includes: adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a two-circuit airfoil; disposing a first slurry into the core die; firing the slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and removing the disposable insert from the integral casting core.

[0062] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

A further embodiment of the foregoing method, wherein the two-circuit airfoil can comprise: a plurality of outer cavities; and a first inner cavity.

[0063] A further embodiment of any of the foregoing methods, wherein the two-circuit airfoil can comprise: an outer circuit that forms at least some of an exterior of the airfoil and defines an outer portion of the plurality of outer cavities; and an inner circuit that defines an inner portion of the plurality of outer cavities and surrounds the first inner cavity.

[0064] A further embodiment of any of the foregoing methods, wherein the inner circuit can completely define the first inner cavity.

[0065] A further embodiment of any of the foregoing methods, wherein the inner circuit can comprise a divider that separates the first inner cavity from a second inner cavity that is completely defined by the inner circuit.

[0066] A further embodiment of any of the foregoing methods, wherein the step of removing the disposable insert can occur during the firing of the first slurry.

[0067] A further embodiment of any of the foregoing methods, wherein the first slurry can comprise ceramic particles.

[0068] A further embodiment of any of the foregoing methods, wherein the method can further comprise: disposing the integral casting core into an investment casting die; injecting a wax into the investment casting die to form a wax component; immersing the wax component into a second slurry to form an outer shell; firing the wax component with the outer shell in a second firing process to form a ceramic shell; removing the wax from the ceramic shell; disposing a molten metal into the ceramic shell; and removing the ceramic shell to yield a molded component.

[0069] A method of forming an integral casting core according to an exemplary embodiment of this disclosure, among other possible things includes: adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a three-zone airfoil; disposing a first slurry into the core die; firing the first slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and removing the disposable insert from the integral casting core.

[0070] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

A further embodiment of the foregoing method, wherein the three-zone airfoil can comprise: a first zone that begins at a leading edge of the three-zone airfoil and includes a first cavity; a second zone that begins at a trailing edge of the three-zone airfoil and includes a second cavity; and a third zone positioned between the first and second zones, the third zone comprising: a third cavity positioned proximate a pressure side of the three-zone airfoil; a fourth cavity positioned proximate a suction side of the three-zone airfoil; and a fifth cavity positioned between the third and fourth cavities.

[0071] A further embodiment of any of the foregoing methods, wherein the second cavity can extend into the third zone.

[0072] A further embodiment of any of the foregoing methods, wherein the method can further comprise: a sixth cavity in the third zone positioned between the second cavity and the pressure side; and a seventh cavity in the third zone positioned between the second cavity and the suction side.

[0073] A further embodiment of any of the foregoing methods, wherein the third zone can further comprise: an eighth cavity positioned between the fifth cavity and the pressure side, adjacent the third cavity; and a ninth cavity positioned between the fifth cavity and the suction side, adjacent the fourth cavity.

[0074] A further embodiment of any of the foregoing methods, wherein the method can further comprise: disposing the integral casting core into an investment casting die; injecting a wax into the investment casting die to form a wax component; immersing the wax component into a second slurry to form an outer shell; firing the wax component with the outer shell in a second firing process to form a ceramic shell; removing the wax from the ceramic shell; disposing a molten metal into the ceramic shell; and removing the ceramic shell to yield a molded component.

[0075] A further embodiment of any of the foregoing methods, wherein the step of removing the disposable insert can occur during the firing of the first slurry.

[0076] A further embodiment of any of the foregoing methods, wherein the first slurry can comprise ceramic particles.

[0077] A method of forming an integral casting core according to an exemplary embodiment of this disclosure, among other possible things includes: adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a quadruple-wall airfoil; disposing a first slurry into the core die, wherein the first slurry comprises ceramic particles; firing the slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and removing the disposable insert from the integral casting core.

[0078] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

A further embodiment of the foregoing method, wherein the quadruple-wall airfoil can comprise: a pressure side wall; a first inner wall spaced apart from the pressure side wall; a second inner wall that is spaced apart from the first inner wall and is positioned opposite of the pressure side wall with respect to the first inner wall; and a suction side wall that is spaced apart from the second inner wall and is positioned opposite of the first inner wall with respect to the second inner wall.

[0079] A further embodiment of any of the foregoing methods, wherein the quadruple-wall airfoil can further comprise: a first cavity positioned between the pressure side wall and the first inner wall; a second cavity positioned between the first inner wall and the second inner wall; and a third cavity positioned between the second inner wall and the suction side wall.

[0080] A further embodiment of any of the foregoing methods, wherein first and second inner walls can terminate at a divider that is positioned proximate to the leading edge.

[0081] A further embodiment of any of the foregoing methods, wherein the step of removing the disposable insert can occur during the firing of the first slurry.

[0082] A further embodiment of any of the foregoing methods, wherein the method can further comprise: disposing the integral casting core into an investment casting die; injecting a wax into the investment casting die to form a wax component; immersing the wax component into a second slurry to form an outer shell; firing the wax component with the outer shell in a second firing process to form a ceramic shell; removing the wax from the ceramic shell; disposing a molten metal into the ceramic shell; and removing the ceramic shell to yield a molded component.

[0083] A method of forming an airfoil with an integral casting core according to an exemplary embodiment of this disclosure, among other possible things includes: adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a two-circuit airfoil; disposing a first slurry into the core die; firing the slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; removing the disposable insert from the integral casting core; disposing the integral casting core into an investment casting die; injecting a wax into the investment casting die to form a wax component; immersing the wax component into a second slurry to form an outer shell; firing the wax component with the outer shell in a second firing process to form a ceramic shell; removing the wax from the ceramic shell; disposing a molten metal into the ceramic shell; and removing the ceramic shell to yield the airfoil.

[0084] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations and/or additional components:

A further embodiment of the foregoing method, wherein the two-circuit airfoil can comprise: a plurality of outer cavities; and a first inner cavity.

[0085] A further embodiment of any of the foregoing methods, wherein the two-circuit airfoil can comprise: an outer circuit that forms at least some of an exterior of the airfoil and defines an outer portion of the plurality of outer cavities; and an inner circuit that defines an inner portion of the plurality of outer cavities and surrounds the first inner cavity.

[0086] A further embodiment of any of the foregoing methods, wherein the inner circuit can completely define the first inner cavity.

[0087] A further embodiment of any of the foregoing methods, wherein the inner circuit can comprise a divider that separates the first inner cavity from a second inner cavity that is completely defined by the inner circuit.

[0088] A further embodiment of any of the foregoing methods, wherein the step of removing the disposable insert can occur during the firing of the first slurry.

[0089] A further embodiment of any of the foregoing methods, wherein the first slurry can comprise ceramic particles.

[0090] While the invention has been described with reference to an exemplary embodiment(s), 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(s) disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A method of forming an integral casting core comprising:

adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a two-circuit airfoil;
disposing a first slurry into the core die;
firing the slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and
removing the disposable insert from the integral casting core.

2. The method of claim 1, wherein the two-circuit airfoil comprises:

a plurality of outer cavities; and
a first inner cavity.

3. The method of claim 2, wherein the two-circuit airfoil comprises:

an outer circuit that forms at least some of an exterior of the airfoil and defines an outer portion of the plurality of outer cavities; and
an inner circuit that defines an inner portion of the plurality of outer cavities and surrounds the first inner cavity.

4. The method of claim 3, wherein the inner circuit completely defines the first inner cavity.

5. The method of claim 3, wherein the inner circuit comprises a divider that separates the first inner cavity from a second inner cavity that is completely defined by the inner circuit.

6. The method of any preceding claim, further comprising:

disposing the integral casting core into an investment casting die;
injecting a wax into the investment casting die to form a wax component;
immersing the wax component into a second slurry to form an outer shell;
firing the wax component with the outer shell in a second firing process to form a ceramic shell;
removing the wax from the ceramic shell;
disposing a molten metal into the ceramic shell; and
removing the ceramic shell to yield a molded component.

7. A method of forming an integral casting core comprising:

adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a three-zone airfoil;
disposing a first slurry into the core die;
firing the first slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and
removing the disposable insert from the integral casting core.

8. The method of claim 7, wherein the three-zone airfoil comprises:

a first zone that begins at a leading edge of the three-zone airfoil and includes a first cavity;
a second zone that begins at a trailing edge of the three-zone airfoil and includes a second cavity; and
a third zone positioned between the first and second zones, the third zone comprising:

a third cavity positioned proximate a pressure side of the three-zone airfoil;
a fourth cavity positioned proximate a suction side of the three-zone airfoil; and
a fifth cavity positioned between the third and fourth cavities.

9. The method of claim 8, wherein the second cavity extends into the third zone.

10. The method of claim 9, further comprising:

a sixth cavity in the third zone positioned between the second cavity and the pressure side; and
a seventh cavity in the third zone positioned between the second cavity and the suction side.

11. The method of any of claims 8 to 10, wherein the third zone further comprises:

an eighth cavity positioned between the fifth cavity and the pressure side, adjacent the third cavity; and
a ninth cavity positioned between the fifth cavity and the suction side, adjacent the fourth cavity.

12. The method of any of claims 7 to 11, further comprising:

disposing the integral casting core into an investment casting die;
injecting a wax into the investment casting die to form a wax component;
immersing the wax component into a second slurry to form an outer shell;
firing the wax component with the outer shell in a second firing process to form a ceramic shell;
removing the wax from the ceramic shell;
disposing a molten metal into the ceramic shell; and
removing the ceramic shell to yield a molded component.

13. A method of forming an integral casting core comprising:

adding a disposable insert to a core die, wherein the disposable insert defines an inner wall in a quadruple-wall airfoil;
disposing a first slurry into the core die, wherein the first slurry comprises ceramic particles;
firing the slurry to form an integral casting core, wherein firing the first slurry occurs after adding the disposable insert to the core die and disposing the first slurry into the core die; and
removing the disposable insert from the integral casting core

14. The method of any preceding claim, wherein the step of removing the disposable insert occurs during the firing of the first slurry.

15. The method of any preceding claim, wherein the first slurry comprises ceramic particles.

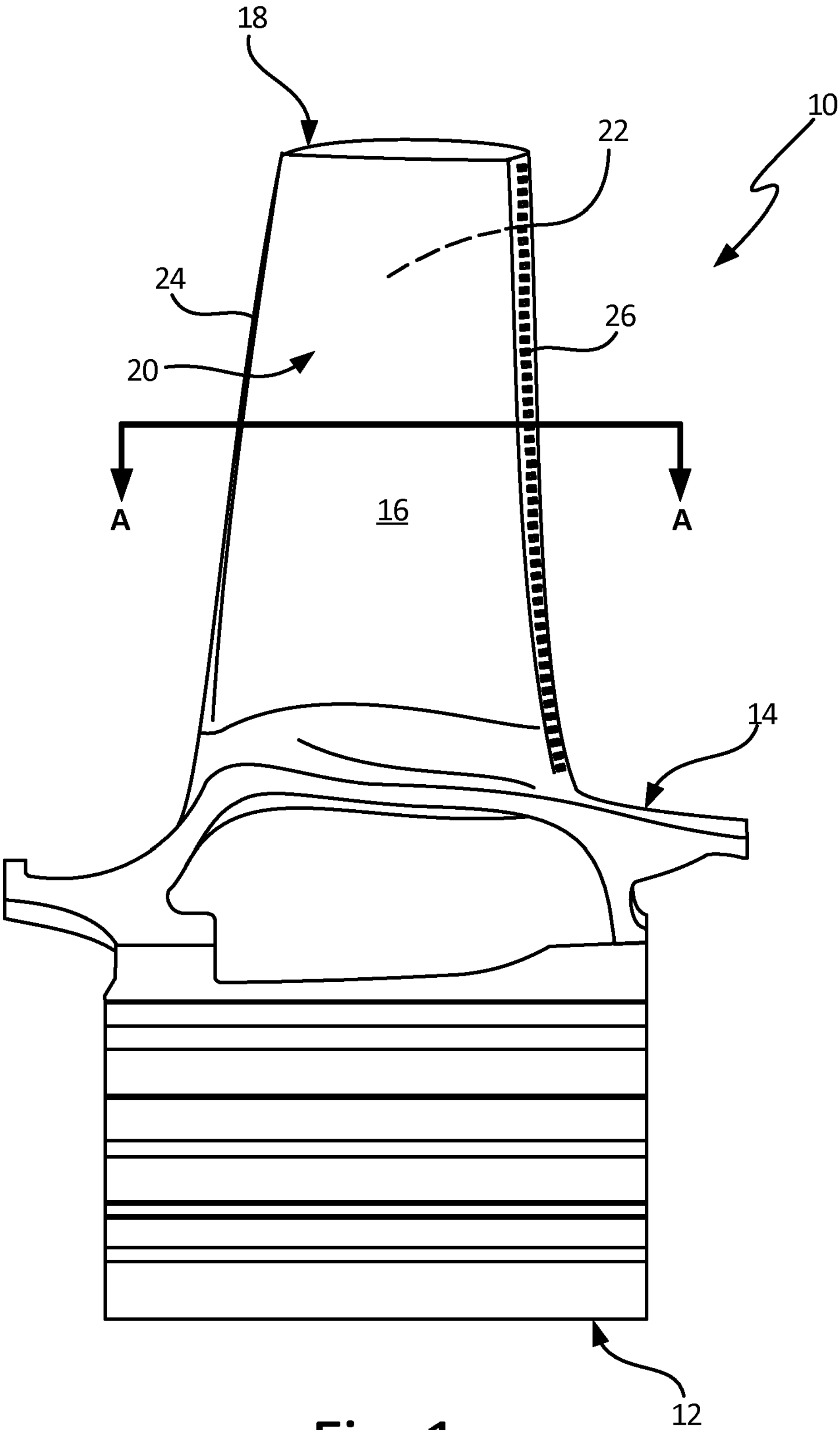


Fig. 1

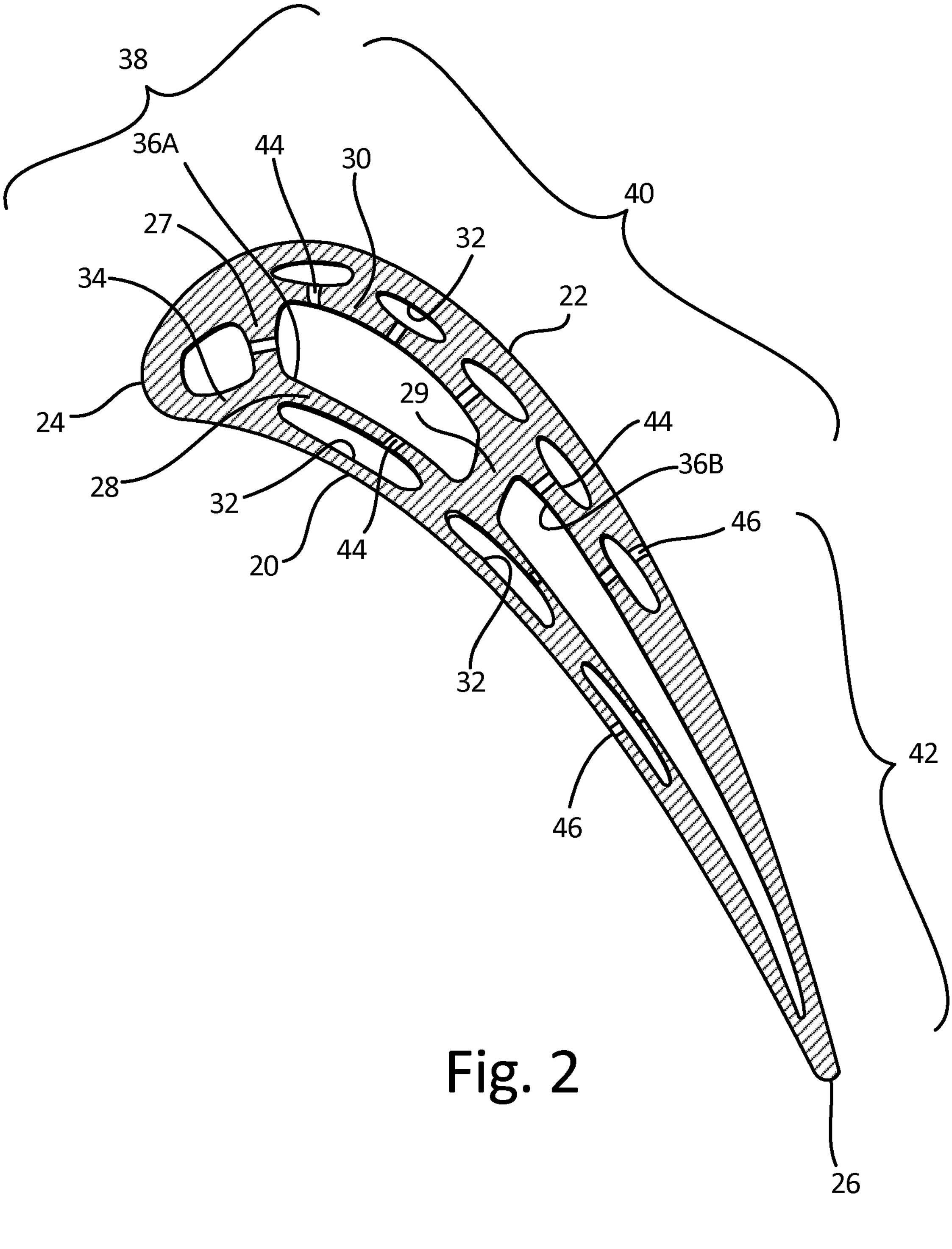


Fig. 2

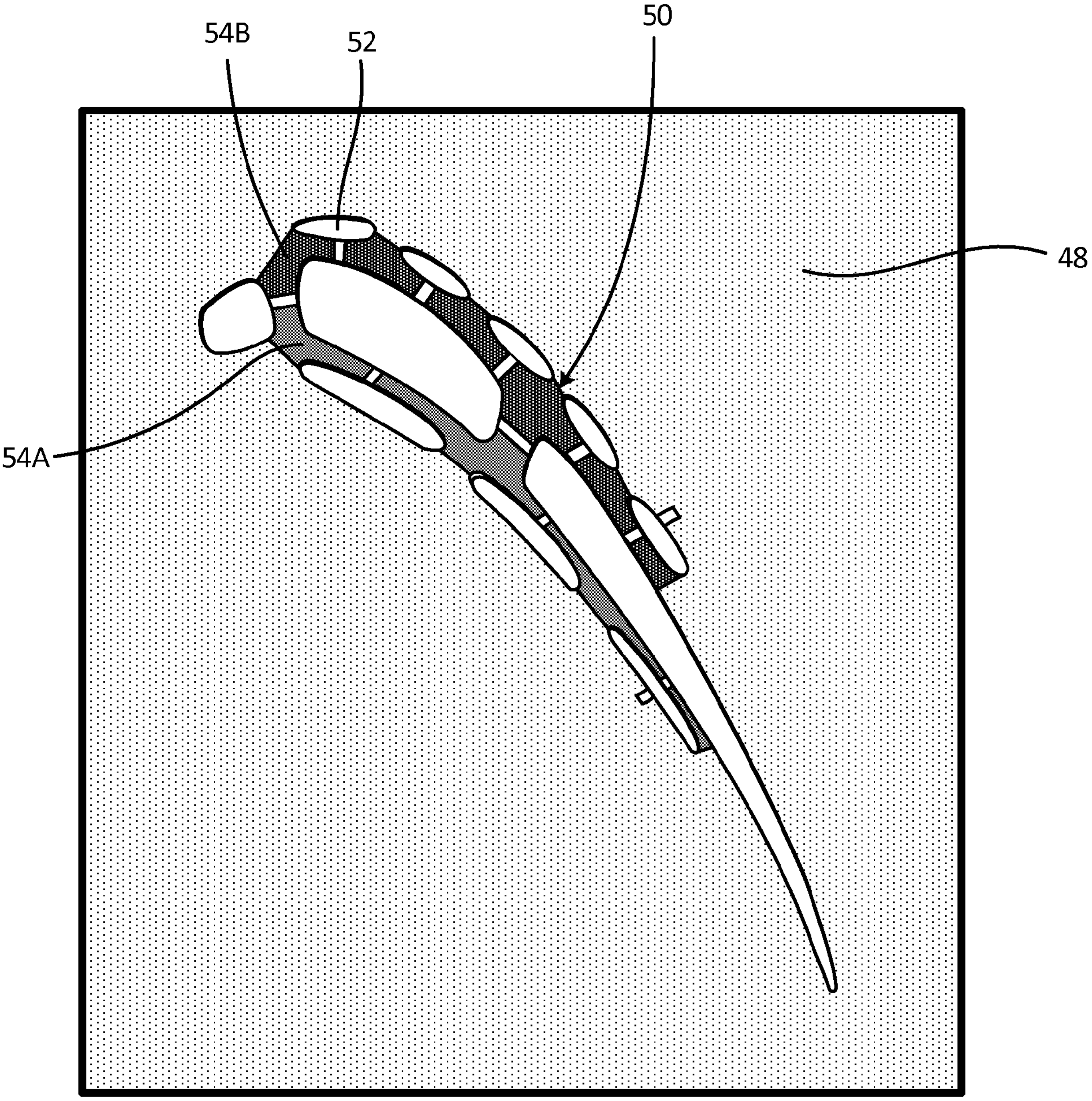


Fig. 3

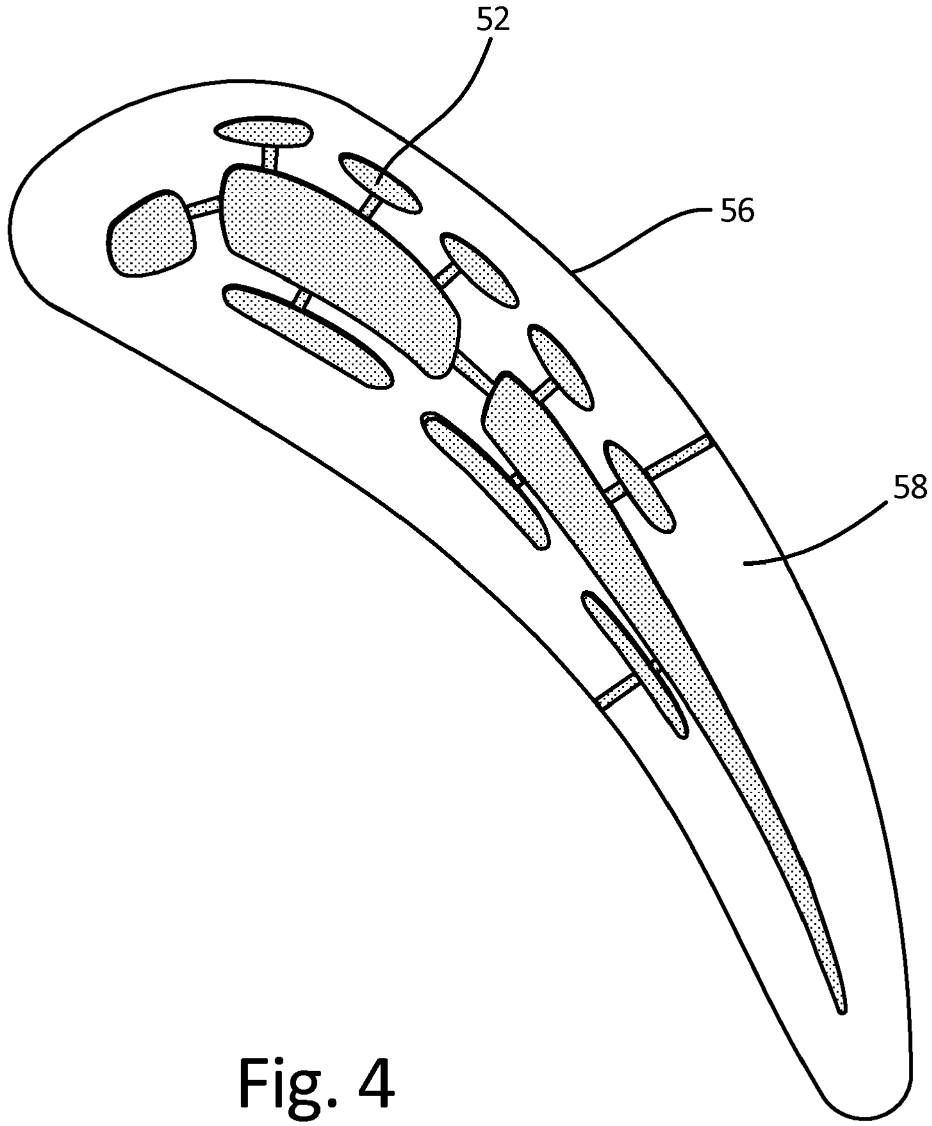


Fig. 4

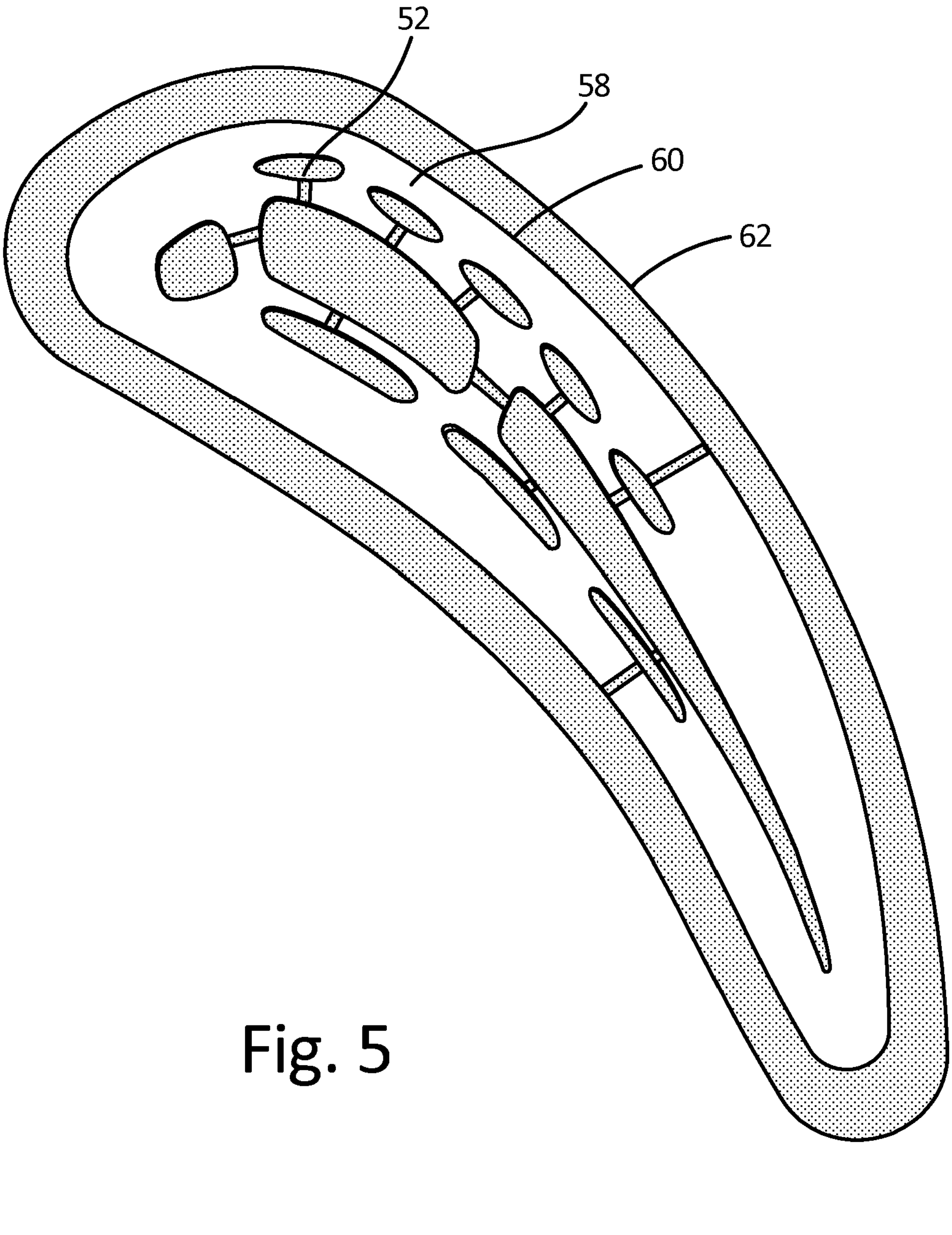


Fig. 5

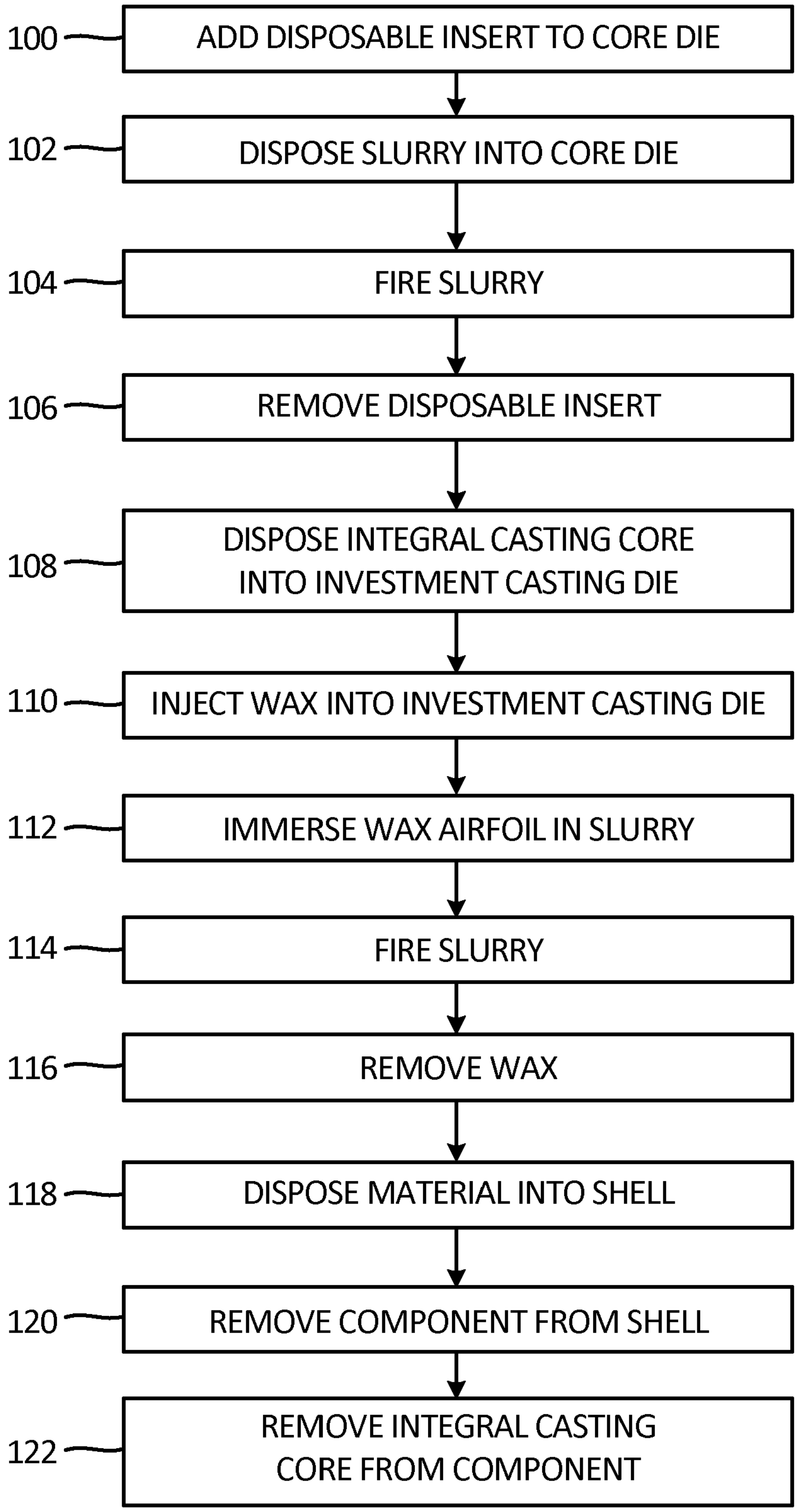

100
ADD DISPOSABLE INSERT TO CORE DIE
102
DISPOSE SLURRY INTO CORE DIE
104
FIRE SLURRY
106
REMOVE DISPOSABLE INSERT
108
DISPOSE INTEGRAL CASTING CORE INTO INVESTMENT CASTING DIE
110
INJECT WAX INTO INVESTMENT CASTING DIE
112
IMMERSE WAX AIRFOIL IN SLURRY
114
FIRE SLURRY
116
REMOVE WAX
118
DISPOSE MATERIAL INTO SHELL
120
REMOVE COMPONENT FROM SHELL
122
REMOVE INTEGRAL CASTING CORE FROM COMPONENT

Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 18 16 1676

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	US 7 624 787 B2 (GEN ELECTRIC [US]) 1 December 2009 (2009-12-01) * column 2 - column 2; figures 1-6 *	1,6,7, 12-15 1-15	INV. B22C9/04 B22C9/10
X Y	US 6 626 230 B1 (WOODRUM HARRY A [US] ET AL) 30 September 2003 (2003-09-30) * figures 1-11 *	1-3,6-9, 12,13,15 1-15	
Y	US 7 448 433 B2 (HONEYWELL INT INC [US]) 11 November 2008 (2008-11-11) * figures 1,4 *	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

B22C
F01D
B28B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	30 May 2018	Baumgartner, Robin

CATEGORY OF CITED DOCUMENTS

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30-05-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 7624787 B2	01-12-2009	CA 2611471 A1	06-06-2008
		EP 1930099 A1	11-06-2008
		JP 2008142777 A	26-06-2008
		US 2008135718 A1	12-06-2008
US 6626230 B1	30-09-2003	AT 350182 T	15-01-2007
		DE 60032824 T2	08-11-2007
		EP 1381481 A2	21-01-2004
		JP 4906210 B2	28-03-2012
		JP 2004504945 A	19-02-2004
		US 6626230 B1	30-09-2003
		WO 0145877 A2	28-06-2001
US 7448433 B2	11-11-2008	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82