METHODS AND MATERIALS FOR ATTACHING CASTING CORES

BACKGROUND OF THE INVENTION

[0001] The invention relates to investment casting. More particularly, the invention relates to investment casting core assemblies.

[0002] Investment casting is commonly used in the aerospace industry. Various examples involve the casting of gas turbine engine parts. Exemplary parts include various blades, vanes, seals, and combustor panels. Many such parts are cast with cooling passageways. The passageways may be formed by sacrificial casting cores.

[0003] Exemplary cores include ceramic cores, refractory metal cores (RMCs), and combinations thereof. In exemplary combinations, the ceramic cores may form feed passageways whereas the RMCs may form cooling passageways extending from the feed passageways through walls of the associated part. It is understood that ceramic cores may be used to form cooling passageways and metal cores may be used to form feed passageways. Ceramic cores may be made by molding a "green" core and then firing to harden. Refractory metal cores may be made by casting or from sheetstock (e.g., by stamping or cutting/forming) or by other suitable methods. The cores may be assembled to each other and secured, for example, with a ceramic adhesive. An exemplary ceramic adhesive is alumina-based. For example, the adhesive may comprise alumina powder and a binder such as colloidal silica.

[0004] The core(s) may be overmolded with a sacrificial material (e.g., a wax) to form a pattern in a shape at least partially corresponding to that of the part to be cast. A shell may be formed over the pattern (e.g., a ceramic shell

formed in a multi-stage stuccoing process). The sacrificial material may be removed (e.g., by a steam dewaxing) leaving the core within a mold chamber formed by the shell. The shell may be fired to harden.

[0005] Molten metal may be poured into the shell and allowed to solidify.

[0006] After this initial casting of the part (e.g., from a nickel- or cobalt-based superalloy), the casting shell and core(s) are destructively removed. Exemplary shell removal is principally mechanical. Exemplary core removal is principally chemical. For example, the cores may be removed by chemical leaching. Exemplary leaching involves use of an alkaline solution in an autoclave. Exemplary leaching techniques are disclosed in US Patents 4,141,781, 6,241,000, and 6,739,380.

SUMMARY OF THE INVENTION

[0007] Accordingly, one aspect of the invention involves a method for attaching a first casting core to a second casting core. A first portion of the first casting core is brought into engagement or close proximity with a second portion of the second casting core. The first and second portions are dipped in a ceramic slurry to form a coating around the first and second portions. The coating is hardened to form a joint between the first and second portions. The resulting composite core may be easier to manufacture than a similarly shaped non-composite core.

[0008] In various implementations, the metallic casting core may comprise a refractory metal-based substrate (e.g., optionally coated). The method may be used to form a turbine blade core assembly or a turbine vane core assembly. The slurry may be heated to harden. The metallic casting core and

ceramic casting core may be vibrated during the introducing. The bringing may be performed with the ceramic casting cores in a green state or in a fired state. The slurry may comprise zircon and aqueous colloidal silica.

[0009] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a flowchart of an exemplary investment casting process.

[0011] FIG. 2 is a view of a pair of ceramic cores.

[0012] FIG. 3 is a view of the cores of FIG. 2 held assembled in a fixture.

[0013] FIG. 4 is a view of the composite core formed from the ceramic cores of FIG. 2 assembled with a metallic core.

[0014] FIG. 5 is a flowchart of the assembly/manufacture steps of the composite core of FIG. 4.

[0015] FIG. 6 is a view of a ceramic core attached to a metallic core.

[0016] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0017] FIG. 1 shows an exemplary method 20 for forming an investment casting mold. Other methods are possible, including a variety of prior art methods and yet-developed methods. One or more metallic core elements are formed 22 (e.g., of refractory metals such as molybdenum and niobium by stamping or otherwise cutting from sheet metal or of alloys or intermetallics containing one or more refractory metals) and coated 24. Suitable coating materials include silica, alumina, zirconia, chromia, mullite and hafnia. Preferably, the coefficient of thermal expansion (CTE) of the refractory metal and the coating are similar. Coatings may be applied by any appropriate line-of sight or non-line-of sight technique (e.g., chemical or physical vapor deposition (CVD, PVD) methods, plasma spray methods, electrophoresis, and sol gel methods). Individual layers may typically be 0.1 to 1 mil thick. Layers of Pt, other noble metals, Cr, Si, W, and/or Al, or other non-metallic materials may be applied to the metallic core elements for oxidation protection in combination with a ceramic coating for protection from molten metal erosion and dissolution.

[0018] One or more ceramic cores may also be formed 26 (e.g., of or containing silica in a molding and firing process). One or more of the coated metallic core elements (hereafter refractory metal cores (RMCs)) are assembled 28 to one or more of the ceramic cores. As noted above, the assembly may include use of a ceramic slurry discussed below. The core assembly is then overmolded 30 with an easily sacrificed material such as a natural or synthetic wax (e.g., via placing the assembly in a mold and molding the wax around it). There may be multiple such assemblies involved in a given mold.

[0019] The overmolded core assembly (or group of assemblies) forms a casting pattern with an exterior shape largely corresponding to the exterior shape of the part to be cast. The pattern may then be assembled 32 to a shelling fixture (e.g., via wax welding between end plates of the fixture). The pattern may then be shelled 34 (e.g., via one or more stages of slurry dipping, slurry spraying, or the like). After the shell is built up, it may be dried 36. The drying provides the shell with at least sufficient strength or other physical integrity properties to permit subsequent processing. For example, the shell containing the invested core assembly may be disassembled 38 fully or partially from the shelling fixture and then transferred 40 to a dewaxer (e.g., a steam autoclave). In the dewaxer, a steam dewax process 42 removes a major portion of the wax leaving the core assembly secured within the shell. The shell and core assembly will largely form the ultimate mold. However, the dewax process typically leaves a wax or byproduct hydrocarbon residue on the shell interior and core assembly.

[0020] After the dewax, the shell is transferred 44 to a furnace (e.g., containing air or other oxidizing atmosphere) in which it is heated 46 to strengthen the shell and remove any remaining wax residue (e.g., by vaporization) and/or converting hydrocarbon residue to carbon. Oxygen in the atmosphere reacts with the carbon to form carbon dioxide. Removal of the carbon is advantageous to reduce or eliminate the formation of detrimental carbides in the metal casting. Removing carbon offers the additional advantage of reducing the potential for clogging the vacuum pumps used in subsequent stages of operation.

[0021] The mold may be removed from the atmospheric furnace, allowed to cool, and inspected 48. The mold may be seeded 50,

if necessary(e.g., by locating a metallic seed in the mold to establish the ultimate crystal structure of a directionally solidified (DS) casting or a single-crystal (SX) casting). Nevertheless the present teachings may be applied to other DS and SX casting techniques (e.g., wherein the shell geometry defines a grain selector) or to casting of other microstructures. The mold may be transferred 52 to a casting furnace (e.g., placed atop a chill plate in the furnace). The casting furnace may be pumped down to vacuum 54 or charged with a non-oxidizing atmosphere (e.g., inert gas) to prevent oxidation of the casting alloy. The casting furnace is heated 56 to preheat the mold. This preheating serves two purposes: to further harden and strengthen the shell; and to preheat the shell for the introduction of molten alloy to prevent thermal shock of the shell and premature solidification of the alloy.

[0022] After preheating and while still under vacuum conditions, the molten alloy is poured 58 into the mold and the mold is allowed to cool to solidify 60 the alloy (e.g., during or after withdrawal from the furnace hot zone). After solidification, the vacuum may be broken 62 and the chilled mold removed 64 from the casting furnace. The shell may be removed in a deshelling process 66 (e.g., mechanical breaking of the shell).

[0023] The core assembly is removed in a decoring process 68 to leave a cast article (e.g., a metallic precursor of the ultimate part). Inventive multi-stage decoring processes are described below. The cast article may be machined 70, chemically and/or thermally treated 72 and coated 74 to form the ultimate part. Some or all of any machining or chemical or thermal treatment may be performed before the decoring.

[0024] FIGS. 2-4 show an exemplary composite core in various stages of manufacture. FIG. 5 is a flowchart of the assembly/manufacture steps. FIG. 2 shows a pair of individually-molded ceramic cores 120 and 122. The exemplary cores have respective main body portions or trunks 124 and 126 and terminal portions 128 and 130. Near respective ends 132 and 134 of the terminal portions, the cores may include mating features 136 and 138. Exemplary mating features are shown as a protuberant projection 136 and complementary compartment 138. Alternative mating features include dovetail and other back-locking features, shiplap features, halflap features, and simple butt features. Although illustrated at terminal portions, the mating features may be otherwise formed (e.g., one or more pairs of mating features at intermediate locations along a core body).

[0025] After molding and optionally after a firing to further harden the cores, the cores 120 and 122 may be assembled to each other. FIG. 3 shows the cores assembled/mated 180 to each other and held by a fixture 140 with their mating features engaged to each other. Exemplary fixtures 140 may include clamps, robotic actuators, and the like.

[0026] The fixture 140 may hold the assembled cores during the application of slurry. Exemplary slurry application includes one or more dippings 182 of the terminal portions in a slurry tank to apply a slurry coating 150. If multiple dippings are used, they may be of the same slurry or different slurries from different tanks to produce a desired layering of the coating 150 (e.g., for maximized strength of joint). The terminal portions may be slightly thinned or recessed relative to the adjacent trunk portions so that the build-up of slurry does not excessively increase core thickness or provide discontinuities therein. During the coating application, the

fixture 140 may hold the engaged portions of the cores in contact or close proximity (e.g., with a gap sufficiently sized to allow a bonding infiltration of the slurry between the two cores).

[0027] After coating application, the coating may be hardened. An exemplary hardening involves drying 184 without further firing. This may be particularly useful with pre-fired ceramic components which are held together with wax pads. For example, an additional ceramic core may be pre-assembled to one of the cores 120 or 122 and positioned with a wax pad. Room temperature drying of the slurry would preserve the pad. Alternative non-firing drying might involve heating at temperatures of up to 95°C. The hardening may, alternatively, include a firing (e.g., at 1200°C or greater) which may also harden the cores 120 and 122 (e.g., if assembled in a green state or an only partially fired state).

[0028] The result of the hardening is to produce a joint 154 of sufficient strength to allow further handling and processing steps as described relative to FIG. 1. As described therein, these may include assembly of the resulting composite ceramic core 160 to one or more other cores such as a refractory metal core 162 (FIG. 4) (e.g., via insertion 186 in a slot cut in the composite core or pre-molded therein).

[0029] Exemplary slurries may be identical or similar to shell coating slurries. Sequences may be altered relative to application sequences for shell coating slurries to provide desired joint strength and joint surface smoothness. For example, shell coating slurry application sequences typically proceed from fine to coarse. Initial fine slurry is applied to a pattern for smoothness and subsequent coarse slurry for strength. However, it may be desired that the last layer of

slurry in the coating 150 be fine for smoothness because the cores generally form internal features whereas the shells generally form external features. Exemplary slurries comprise a combination of zircon and aqueous colloidal silica along with appropriate surfactants and other agents (e.g., for promoting bubble rupture).

[0030] Variations include use of the slurry coating in combination with a ceramic adhesive in the joint. The adhesive may be introduced during core assembly. Exemplary ceramic adhesives are available from Cotronics Corporation of Brooklyn, New York, under the trademark RESBOND. Use of ceramic adhesive may be particularly appropriate with pre-fired ceramic cores. The ceramic adhesive increases bond strength and may further avoid the need for a subsequent high temperature firing.

[0031] Such adhesive may also be appropriate when the dipped assembly includes metallic or other non-ceramic cores which may be adversely affected by a high temperature firing. For example, FIG. 6 shows the assembly of a ceramic core 200 with a refractory metal core 202. A portion 204 of the refractory metal core is positioned within a slot 206 of a ceramic core and retained at least partially by a ceramic adhesive 208. A slurry coating 210 may surround the junction of these two cores to form a joint. The slurry 210 may be applied as described above. If required by physical constraints or otherwise appropriate, a portion of one or both of the cores may be masked during slurry application (e.g., spraying, painting, or dipping) or may be cleaned of slurry after such application. As with the joint between ceramic cores, the overdipping of the RMC-ceramic core joint isolates the unfired ceramic adhesive (if any) from contact with the casting alloy to avoid adverse chemical interaction.

[0032] One or more embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, the principles may be implemented as modifications of existing or yet-developed processes in which cases those processes would influence or dictate parameters of the implementation. Accordingly, other embodiments are within the scope of the following claims.

CLAIMS

What is claimed is:

1. A method for attaching a first casting core to a second casting core comprising:

bringing a first portion of the first casting core into engagement with or close proximity to a second portion of the second casting core;

dipping the first portion and second portion in a slurry to form a coating; and

hardening the coating to join or further join the first and second casting cores.

2. The method of claim 1 further comprising:

bringing a third portion of a third casting core into engagement with or close proximity to a fourth portion of at least one of the first and second cores and wherein said dipping, or another dipping, comprises dipping the third and fourth portions.

3. The method of claim 1 further comprising:

attaching at least one additional casting core to at least one of the first and second casting cores.

4. The method of claim 1 wherein:

the bringing comprises contacting and holding in contact; and

the dipping is performed after the bringing.

5. The method of claim 1 wherein:

the bringing comprises providing a ceramic adhesive between the first portion and second portion; and

the dipping is performed after the bringing.

6. The method of claim 1 wherein:

the dipping comprises multiple dippings in different slurries; and

at least one of the dippings is performed after the bringing.

7. The method of claim 1 wherein:

the bringing comprises contacting in a fired state; and

the hardening comprises drying and does not comprise firing.

8. The method of claim 1 wherein:

the bringing comprises contacting in a green state; and

the hardening comprises firing with the first and second cores to also harden the first and second cores.

9. The method of claim 1 wherein:

the coating fully encircles the first and second portions at a junction.

10. The method of claim 1 further comprising:

molding the first and second casting cores.

11. The method of claim 1 wherein:

the bringing comprises forming a joint selected from the group consisting of: shiplap, half lap, back-locked protuberance/recess, and tongue/groove.

12. The method of claim 1 further comprising:

inserting an insertion portion of a metallic casting core into a receiving portion of the joined first and second casting cores.

13. The method of claim 1 used to form a turbine blade core, a turbine vane core, a seal core or a combustor core.

14. The method of claim 1 further comprising:
the hardening comprises heating.

15. The method of claim 1 wherein the slurry comprises zircon and aqueous colloidal silica.

16. The method of claim 1 wherein:
the slurry has an aqueous colloidal silica content of 20-30%, by weight, of a zircon content.

17. The method of claim 1 wherein:
the slurry comprises a surfactant.

18. The method of claim 1 further comprising:
molding the first casting core; and
forming the second casting core from a metallic sheet.

19. The method of claim 1 wherein:
the first casting core comprises a molded ceramic; and
the second casting core comprises a metallic member.

20. A method for investment casting comprising:
attaching, according to claim 1, first and second casting cores;
molding a sacrificial material partially over the first and second casting cores;
applying a shell to the sacrificial material;

removing the sacrificial material from the shell;

delivering molten metal to the shell at least partially in place of the sacrificial material;

allowing the molten metal to solidify;

removing the shell and first and second casting cores from the solidified metal.

21. A method for attaching a first casting core to a second casting core comprising:

bringing a first portion of the first casting core into engagement with or close proximity to a second portion of the second casting core in a first relative position;

holding the first casting core and second casting core to maintain said first relative position;

dipping the first portion and second portion in a slurry to form a coating; and

hardening the coating to join or further join the first and second casting cores.

22. The method of claim 21 wherein:

the dipping and a portion of the hardening occur during the holding.

23. A method for attaching a first casting core to a second casting core comprising:

bringing a first portion of the first casting core into engagement with or close proximity to a second portion of the second casting core in a first relative position;

applying a slurry coating over the first portion and second portion in a to form; and

hardening the slurry coating to join or further join the first and second casting cores.

24. The method of claim 23 further comprising:

holding the first casting core and second casting core to maintain said first relative position during at least portions of said applying and hardening.

25. The method of claim 23 wherein:

the coating fully encircles the first and second portions at a junction.