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(54) **BONDCASTING PROCESS USING INVESTMENT AND SAND CASTING**

(57) A method of forming a component having a plurality of parts constructed from at least two different materials includes forming a first part made from a first material, placing a sandcasting pattern in a sand molding box, filling the sand molding box with sand, removing the sandcasting pattern from the sand molding box, placing

the first part in a first portion of a void in the sand with the void formed by the removal of the sandcasting pattern, filling a remaining area of the void with a second material, and allowing the second material to solidify to form a second part.

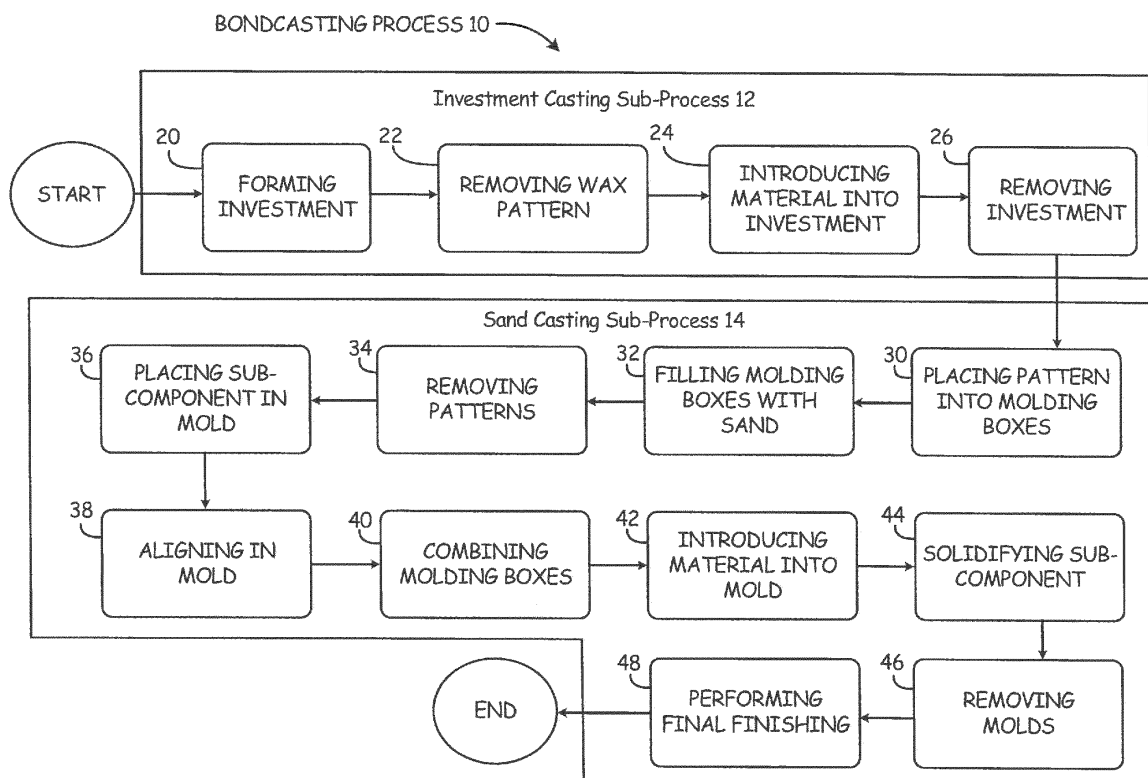


Fig. 1

Description

BACKGROUND

[0001] The present disclosure relates to a method of manufacturing and, more particularly, a method of casting an apparatus constructed from at least two, but possibly many, different materials.

[0002] It is desirable to form complex apparatuses from multiple materials where unique properties of one material are needed in one area of the finished apparatus while unique properties of another material are needed in another area of the finished apparatus. When multiple materials are needed, combining these sub-components into one final finished apparatus becomes troublesome. The sub-components can be manufactured separately and fastened to one another through rivets, bolts, or welds, but that requires additional manufacturing steps that are time consuming and inefficient. Another process includes manufacturing the sub-components made from one material and then investment casting or die casting other sub-components made from a different material around the first sub-components. This process is only applicable when the first sub-components are made from a material that can withstand investment or die casting without melting or becoming damaged or when the second sub-component has a configuration suited for investment or die casting (the sub-component is not too large and/or does not have features that cannot be investment or die casted). Additionally, the investment or die casting processes may need to be altered to accommodate the inclusion of the first sub-components that are not being investment or die casted.

[0003] Therefore, there is a need for a process of forming a finished apparatus made from multiple materials that is more efficient and less time consuming.

SUMMARY

[0004] A method of manufacturing an apparatus includes forming a first sub-component having a locking feature with the first sub-component being constructed from a superalloy (or another high temperature alloy), placing the first sub-component into a void in sand in a sand molding box with the void having a first portion shaped like the first sub-component and a second portion shaped like a second sub-component and the first sub-component sitting in the void such that the locking feature is adjoining the second portion and the second portion is unoccupied by the first sub-component, introducing a second material in a fluidic state into the second portion so that the second material is adjacent to at least a part of the locking feature, and allowing the second material to solidify to form the second sub-component adjoining the locking feature.

[0005] A method of making an apparatus constructed from at least two different materials includes investment casting a first sub-component constructed from a first

material with the first sub-component having a locking feature, placing a first pattern in sand to create a first sand casting mold, placing a second pattern in sand to create a second sand casting mold, removing the first pattern and the second pattern, positioning the first sub-component in a first impression in the first sand casting mold with the first impression being sized to house at least a portion of the first sub-component and the first sub-component being positioned so that the locking feature is adjoining a second impression in the first sand casting mold that has the same dimensions as at least a portion of a second sub-component, assembling the first sand casting mold and the second sand casting mold so that the first sub-component is within a first cavity having the same dimensions as the first sub-component and a second cavity having the same dimensions as the second sub-component is formed adjacent to the locking feature, introducing a second material in a fluidic state into the second cavity to form the second sub-component, and solidifying the second material within the second cavity adjoining the locking feature.

[0006] A method of forming a component having a plurality of parts constructed from at least two different materials includes forming a first part made from a first material, placing a sandcasting pattern in a sand molding box, filling the sand molding box with sand, removing the sandcasting pattern from the sand molding box, placing the first part in a first portion of a void in the sand with the void formed by the removal of the sandcasting pattern, filling a remaining area of the void with a second material, and allowing the second material to solidify to form a second part.

[0007] The present summary is provided only by way of example and not limitation. Other aspects of the present disclosure will be appreciated in view of the entirety of the present disclosure, including the entire text, claims, and accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

FIG. 1 is a flow chart of a bondcasting process.

FIG. 2A is a cross-section of a portion of a mold used in the bondcasting process.

FIG. 2B is a cross-section of the mold in FIG. 2A with a portion of a first sub-component of an apparatus. FIG. 2C is a cross-section of a portion of the finished apparatus constructed through use of the mold in FIG. 2A.

FIG. 3 is a cross-section of a portion of a finished apparatus constructed through the bondcasting process having another embodiment of a locking feature.

FIG. 4 is a cross-section of a portion of a finished apparatus constructed through the bondcasting process having yet another embodiment of a locking feature.

FIG. 5A is a cross-section of a portion of a turbine exhaust case constructed through the bondcasting process.

FIG. 5B is a cross-section of a portion of the turbine exhaust case of FIG. 3A taken along section line B-B.

[0009] While the above-identified figures set forth embodiments of the present disclosure, other embodiments are also contemplated, as noted in the discussion. In all cases, this disclosure presents the invention by way of representation and not limitation. It should be understood that numerous other modifications and embodiments can be devised by those skilled in the art, which fall within the scope and spirit of the principles of the invention. The figures may not be drawn to scale, and applications and embodiments of the present invention may include features, components, and steps not specifically shown in the drawings.

DETAILED DESCRIPTION

[0010] A method entitled "bondcasting" is disclosed herein that can include elements of the investment casting process and the sand casting process and introduces new elements to cast a finished apparatus that has sub-components constructed from multiple materials. The bondcasting process does not require the sub-components to be welded, riveted, bolted, or otherwise fastened to one another after the bondcasting process is complete because the sub-components are locked together through mechanical engagements (the geometry of the sub-components holds the sub-components stationary relative to one another). The bondcasting process can be performed even if a sub-component is constructed from a material that has a relatively high melting point, like a superalloy (such as a nickel based superalloy), and/or if a sub-component requires hollow features or an opening within the sub-component. The bondcasting process can also be performed even if a sub-component is too large to be efficiently constructed through another casting process, such as die casting. Additionally, the bondcasting process is flexible and allows for easy adjustment to produce sub-components that are closer to the desired configuration because the pattern and molds used to make the finished apparatus can be formed and altered more easily than other processes. This flexibility is important when multiple sub-components are being constructed together to form a finished apparatus.

[0011] While the bondcasting process described below discusses a summary of the investment casting process (which occurs before the steps of the sand casting sub-process of the bondcasting process), some steps of the investment casting process can be added or omitted. Additionally, the sub-component does not need to be constructed through the investment casting process and can be constructed through another process, such as forging. Likewise, while the bondcasting process described below discusses a version of the sand casting process with

modifications and additions, some steps of the sand casting process can be added or omitted.

[0012] FIG. 1 is a flow chart of an embodiment of a bondcasting process. Bondcasting process 10 is separated into investment casting sub-process 12, which includes some steps that are related to the industry-known investment casting process, and sand casting sub-process 14, which includes some steps that are related to the industry-known sand casting process. Both investment casting sub-process 12 and sand casting sub-process 14 have additional and/or modified steps that accommodate bondcasting process 10 and distinguish bondcasting process 10 from known processes. Also, bondcasting process 10 can omit investment casting sub-process 12 and instead include another sub-process used to construct a first sub-component (known as the investment cast sub-component below).

[0013] Investment casting sub-process 12 of bondcasting process 10 includes the steps of forming the investment 20, removing the wax pattern from the investment 22, introducing the investment casting material into the investment 24, and removing the investment 26.

[0014] Sand casting sub-process 14 of bondcasting process 10 includes placing the pattern into the molding boxes 30, filling the molding boxes with sand 32, removing the pattern to form the molds 34, placing the investment cast sub-component in the mold 36, aligning the investment cast sub-component 38, combining the molding boxes to create a complete mold 40, introducing the sand casting material into the mold 42, solidifying the sand cast sub-component 44, removing the molding boxes and molds 46, and performing the final finishing 48.

[0015] Investment casting sub-process 12 can begin by forming the investment 20. To form the investment 20, a wax pattern can be constructed (through the use of a master pattern and/or master die). Then the wax pattern is encapsulated with the investment, which can include coating the wax pattern with slurry, stuccoing (covering) the coating/wax pattern with a powder/particulate (usually a ceramic based particulate), and hardening the coating/stucco. The coating/stucco should completely and fully encapsulate the wax pattern so that the coating/stucco has the same inner geometry as an outer geometry of the wax pattern (the coating/stucco is the negative of the dimensions of the wax pattern). These steps can be repeated as needed to arrive at an investment (which is the coating/stucco shell) that is sufficiently thick and structurally supportive to withstand the remaining steps of investment casting sub-process 12.

[0016] Removing the wax pattern from the investment 22 is then executed. During this process, the wax pattern is melted and/or vaporized to remove it from within the investment. The method used to remove the wax pattern from the investment depends on the material used to create the wax pattern and the resiliency of the investment, but removal of the wax pattern should be done in such a way so as to not disturb the inner geometry of the investment.

[0017] Introducing the investment casting material into the investment 24 is usually performed by pouring an investment casting material, which is the material used to make the desired sub-component (known as the investment cast sub-component), into a void in the investment that was previously occupied by the wax pattern. To pour the investment casting material into the void in the investment, the investment casting material should be in a fluidic state, likely at an elevated temperature. The investment casting material can be a variety of materials, including a metallic material, a superalloy (such as a nickel based superalloy), or any other desired material that is able to be melted, poured into the investment, and hardened to form the investment cast sub-component. The temperature needed to liquefy/melt the casting material can govern the materials used to make the investment, for the investment must be suited to handle the elevated temperature of the investment casting material and the stresses incurred during the cooling of the investment casting material. After the investment casting material is within the investment, the investment casting material is cooled so that it hardens into a solid in the shape of the previously removed wax pattern (the solid is known as the investment cast sub-component).

[0018] Once the investment cast sub-component has hardened, removing the investment 26 separates the investment (the hardened coating/stucco) from the investment cast sub-component. The investment can be removed through hammering, blasting, vibrating, water-jetting, chemical dissolving, and/or other processes. Removal of the investment results in the investment cast sub-component remaining without the investment (the coating/stucco shell). Depending on the configuration of the investment cast sub-component, final finishing, such as grinding, can be performed as desired to arrive at the final finished investment cast sub-component. The final design of the total component (the finished apparatus made through bondcasting process 10, which includes the sub-component made through investment casting sub-process 12 along with the sub-component made through sand casting sub-process 14) may call for multiple investment cast sub-components. If multiple investment cast sub-components are required, the multiple pieces can go through investment casting sub-process 12 together by being attached to a common structural support (known as a tree), put through the investment process together, and separated after the investment has been removed.

[0019] As mentioned above, investment casting sub-process 12 can be used to construct a sub-component from a material that has a relatively high melting point, like a superalloy (such as a nickel based superalloy). Investment casting sub-process 12 is also used when the investment cast sub-component requires hollow features or an opening within the investment cast sub-component. Additionally, investment casting sub-process 12 is used to preserve the chemical and physical properties of the investment casting material to arrive at a material

composition that exhibits desired characteristics, such as desired metallic grain structure (e.g., single crystal grain structure). As discussed below with regards to sand casting sub-process 14 of bondcasting process 10, the investment cast sub-component (or multiple sub-components) is incorporated into sand casting sub-process 14 to create a finished apparatus constructed from more than one material.

[0020] Bondcasting process 10 can omit investment casting sub-process 12 and can instead include another sub-process, such as forging or permanent mold casting, to form the sub-component that will be inserted into the mold during sand casting sub-process 14. Also, multiple sub-components that will be inserted into the mold during sand casting sub-process 14 can be formed through different sub-processes, such as one sub-component made through investment casting sub-process 12 and another sub-component made through forging, permanent mold casting, or another sub-process. Thus, when discussing sand casting sub-process 14 or the embodiments in FIGS. 2A-5B below, the investment cast component can be formed through another sub-process.

[0021] During sand casting sub-process 14 of bondcasting process 10, the first step is placing the pattern into the molding boxes 30. In this step, a pattern, which is a replica of the finished apparatus having the same dimensions as the finished apparatus, is placed into a molding box. The pattern is shaped such that when sand is filled around the pattern and the pattern is removed, a void is left behind that is a replica of the finished apparatus. The various methods for constructing the pattern are known in the industry and include the use of a master die and/or etching or machining the pattern directly into a form. The pattern can be two pieces, known as the cope and the drag, that each include a portion of the replica having the same dimensions as part of both the investment cast sub-component and the sand cast sub-component (the two patterns are used in a first sand molding box and a second sand molding box and the two sand molding boxes and then brought together). The pattern can be made from a variety of materials, including wood, plastic, metal, or another material. Aside from the portion of the pattern that is the replica of the finished part, each pattern also includes planar extending surfaces that, when combined with the molding boxes (discussed below), create a box-like structure that is able to hold sand to create the mold. The portion of the pattern that is the replica of the finished apparatus may need to be configured to form a void that is slightly larger than the desired finished apparatus to account for contraction of the sand casting material during solidification/cooling (the pattern may need to have slightly larger dimensions than the finished apparatus). Because only the sand casting material may contract during sand casting sub-process 14, it may be necessary only for the void that will be filled with the sand casting material to be enlarged. Each pattern is placed into a corresponding molding box, which usually has four sides forming a rectangle. The pattern

attaches to the four sides and forms a fifth side which, together with the four sides, creates a box into which sand may be introduced and contained to create the mold. The pattern is attached to the four sides in such a manner that the portion of the replica of the finished apparatus extends into the sand molding box. Generally there are two molding boxes, but other configurations can have just one molding box or more than one molding box.

[0022] Once the molding boxes have been assembled, filling the molding boxes with sand 32 is performed to create the mold. With each of the two patterns forming one side of each of the molding boxes (the first molding box and the second molding box), the molding boxes are completely filled with sand and packed so that when the patterns are removed, an indent remains in each of the sand-filled molding boxes that has a portion of the same dimensions as the finished apparatus such that when the first molding box and second molding box are combined, the indent forms a void with the same dimensions as the finished apparatus. As discussed in the next step, the packed sand with the indent caused by the pattern is known as the mold.

[0023] The "sand" used to fill the molding boxes to create the molds does not necessarily have to be pure silica or calcium carbonate sand, for "sand" is an industry term of art. The sand material can be a variety of materials and/or mixtures, such as a mixture that includes silica sand, chromite sand, zircon sand, olivine, staurolite, graphite, bentonite (clay), water, inert sludge, anthracite, adhesive, binders, oil, resin, cushioning material, reducing agents, iron oxide powder, sodium silicate, synthetic sand, or other materials. The sand should collectively form a substance that can completely form to the shape of the pattern and sustain that shape after the pattern has been removed from the molding boxes and while the void in the mold is filled with the investment cast sub-component and the sand casting material. After the molding boxes are filled with sand, the sand can be left to harden or may undergo further treatment to ensure the sand hardens (such as heating).

[0024] Then, removing the patterns from the molding boxes 34 is executed. The patterns are each removed from the molding boxes so that the molding boxes are left behind and a mold (the remaining formed sand structure) is formed in the sand in each molding box with each mold having a void (the indent left in the mold by the pattern). The molds should be a negative replica of the finished apparatus such that the voids formed by each of the molds should have the same dimensions as a portion of the finished apparatus such that when the molds are brought together the void formed has the same dimensions as the finished apparatus.

[0025] Because the patterns can be made from a variety of materials that are easily manipulated; such as wood, plastic, plaster, and others; and the molds are made from sand or another material that is easily formed, the patterns and molds can be easily adjusted if the fin-

ished apparatus needs to have a different configuration than what was intended in the original design. Therefore, bondcasting process 10 is flexible and allows for adjustment on the fly (i.e., after bondcasting process 10 has begun) without the need to scrap the partially-constructed cub-components, which increases efficiency and reduces time and cost.

[0026] After the patterns are removed to form the molds in the sand and leave behind the void having the same dimensions as the finished apparatus, placing the investment cast sub-component in the mold 36 is performed. The investment cast sub-component is placed in one of the molds (to fill at least a portion of the void) in one of the molding boxes, for the two molding boxes are separate from one another up until a subsequent step (when the first sand molding box and the second sand molding box are combined). Here, the investment cast sub-component is positioned in the void in one mold, which has a portion of the same shape as the investment cast sub-component and the sand cast sub-component. The void should be sized so the mold in the molding boxes is not disturbed (the sand does not shift) by the placement of the investment cast sub-component, and the sand should provide sufficient support in the mold to support the investment cast sub-component.

[0027] Next, aligning the investment cast sub-component in the mold 38 is performed. A number of different pieces, including multiple investment cast sub-components, can be placed in the void, with the different investment cast sub-components being carefully aligned in the void to produce a finished apparatus with multiple investment cast sub-components adjoining the sand cast sub-component (as shown in FIG. 5A). As described further below, one or more of the investment cast sub-components can include one or multiple locking features having a variety of configurations, such as projections, grooves, or other configurations (shown in FIGS. 2C, 3, 4, 5A, and 5B) that adjoin or extend outward into a remaining portion of the void (the portion not filled by the investment cast sub-component(s)) so that when the sand casting material is introduced into the remaining portion of the void and solidifies, the locking feature and the sand cast sub-component form a mechanical engagement that prevents movement of the investment cast sub-component relative to the sand cast sub-component. Depending on the configuration of the sand cast sub-component, other features can be aligned in the remaining portion of the void, such as cores, which are features that are used to produce cavities in the sand cast sub-component. These features are then removed after the sand cast sub-component solidifies to leave behind cavities in the sand cast sub-component.

[0028] With the investment cast sub-component on the mold (in the void) in one of the molding boxes, combining the molding boxes to create a complete mold 40 is performed to create a fully enclosed void that has the same dimensions as the sand cast sub-component. Combining the molding boxes to create a complete mold 40 should

be done with care so that the mold and the void are not disturbed (the sand does not shift). The remaining portion of the void can be adjoining the investment cast sub-component and can have within it one or multiple locking features and/or other features (as discussed above). The sand should be structurally sufficient to allow for movement and combining of the molding boxes without the sand shifting and altering the molds.

[0029] Introducing the sand casting material into the mold 42 is performed to create the sand cast sub-component having the same shape as the remaining portion of the void formed by the complete mold (the combination of the mold in the first sand molding box and the mold in the second sand molding box). The sand casting material can be introduced into the void through a hole in the sand that extends from the surface of the molding box to the void. The sand casting material used to fill the void can be a variety of materials, such as metal, an alloy, a plastic, or a resin. The material can have a melting point equal to or less than the melting point of the investment cast sub-component to ensure that the investment cast sub-component does not melt when the high temperature liquefied/molten sand casting material is introduced into the void adjoining the investment cast sub-component. If the temperature of the sand casting material is close to the melting point of the investment cast sub-component when it is introduced into the void, a metallurgical or semi-metallurgical bond can form between the investment cast sub-component and the sand cast sub-component due to partial or complete melting of the surface of the investment cast sub-component adjoining the sand cast sub-component (in addition to a mechanical engagement). If the temperature of the sand casting material is significantly less than the melting point of the investment cast sub-component when it is introduced into the void, no melting of the investment cast sub-component will result and only a mechanical engagement (due to the locking feature) is formed.

[0030] After the sand casting material is introduced into the mold and in place in the void, solidifying the sand cast sub-component 44 ensures that the sand casting material takes the shape of the remaining void to form the desired configuration of the finished apparatus. The sand cast sub-component can be allowed to solidify on its own, or various measures can be taken to ensure the sand casting material of the sand cast sub-component solidifies properly to preserve the chemical and physical properties of the sand cast sub-component. If the investment cast sub-component has a locking feature (or multiple locking features), the sand casting material is allowed to solidify adjacent to the locking feature such that the configuration of the solidified sand cast sub-component and the locking feature form a bond that prevents the sand cast sub-component and the investment cast sub-component from moving relative to one another. The mechanical engagement formed between the locking feature and the sand cast sub-component is a result of the geometry of both, which prevents the two from moving

relative to one another.

[0031] Once the sand cast sub-component has solidified, removing the molds and molding boxes 44 is performed. With the sand cast sub-component solidified and in place adjacent to the investment cast sub-component, the molds, which are constructed from sand, and the molding boxes are separated from the finished apparatus. Usually, the molding boxes can be separated from the sand, molds, and finished apparatus without much difficulty. Depending on the composition of the sand, various means of removing the sand can be used, including hammering, blasting, vibrating, water-jetting, chemical dissolving, and/or other processes.

[0032] After the sand is removed, performing the final finishing 46 is done, if needed, on the finished apparatus (which includes the investment cast sub-component and the sand cast sub-component) to remove any imperfections. The final finishing can be done through grinding or another process, such as cleaning the finished apparatus with a chemical solution.

[0033] As mentioned above, bondcasting process 10 results in a finished apparatus that has multiple sub-components made from different materials. Bondcasting process 10 enables the construction of a finished apparatus having materials that are not able to be incorporated into a finished apparatus through another process without the need for costly and time consuming fabrication through welding, bolting, or otherwise fastening the sub-components together. The differing sub-components, referred to above as the investment cast sub-component(s) and the sand cast sub-component, can be secured to one another through one or multiple locking features. The locking feature can have a variety of configurations, with some nonlimiting embodiments provided in FIGS. 2C, 3, and 4.

[0034] FIG. 2A is a cross-section of a portion of molds 50 used in bondcasting process 10, FIG. 2B is a cross-section of the portion of molds 50 with a first sub-component of a finished apparatus, and FIG. 2C is a cross-section of finished apparatus 59 constructed through the use of molds 50 in FIG. 2A.

[0035] FIG. 2A shows a portion of molds 50 (first mold 50A and second mold 50B) having void 53 with first portion 52 (which will house the investment cast sub-component) and second portion 54 (which will house the sand cast sub-component). As shown in the illustrated embodiment, first mold 50A and second mold 50B each have a part of first portion 52 and second portion 54, which is formed by the two patterns discussed in bondcasting process 10 above. After the two patterns (not shown) are removed, first mold 50A and second mold 50B remain behind, with first mold 50A within the first sand molding box (not shown) and second mold 50B within second sand molding box (not shown). While FIG. 2A shows first mold 50A adjacent to second mold 50B (to show void 53), the two molds would not be adjacent to one another until combining the molding boxes to create the molds 40, which is after the investment cast sub-component is

placed in first portion 52, which is shown in FIG. 2B.

[0036] FIG. 2B shows a portion of molds 50 (first mold 50A and second mold 50B) having void 53 with investment cast sub-component 62 (within first portion 52, hidden by investment cast sub-component 62) and second portion 54. Investment cast sub-component 62 includes locking feature 64 (with projection 64A and end 64B) and hollow feature 66. Investment cast sub-component 62 will be described in greater detail in regards to FIG. 2C. FIG. 2B shows investment cast sub-component 62 within first portion 52 of void 53, with locking feature 64 extending into second portion 54. First portion 52 should have a similar shape as investment cast sub-component 62 so that molds 50 are not disturbed when investment cast sub-component 62 is placed within first portion 52 during bondcasting process 10.

[0037] FIG. 2C includes finished apparatus 59 having sand cast sub-component 60 and investment cast sub-component 62. Investment cast sub-component 62 has locking feature 64 (with projection 64A and end 64B) and hollow feature 66.

[0038] Investment cast sub-component 62 is formed through investment casting sub-process 12 of bondcasting process 10 and is configured to include locking feature 64 having projection 64A, which extends away from the body of investment cast sub-component 62, and end 64B, which extends away from projection 64A and provides an extension around which sand cast sub-component 60 can solidify to hold sand cast sub-component 60 and investment cast sub-component 62 stationary relative to one another. During bondcasting process 10, investment cast sub-component 62 is placed and then aligned within the mold such that locking feature 64 extends into second portion 54 of void 53, which is then filled with the second casting material to form sand cast sub-component 60 around end 64B, producing a mechanical engagement. As shown in FIGS. 2A and 2B, sand would be in place in the space between sand cast sub-component 60 and investment cast sub-component 62 during some of the steps of sand casting sub-process 14 of bondcasting process 10 to ensure that finished apparatus 59, as seen in FIG. 2C, includes such a space. As mentioned above, the temperature of the sand casting material when introduced into second portion 54 of void 53 can be varied to cause the surface of locking feature 64 to melt such that when sand cast sub-component 60 and locking feature 64 solidify, a metallurgical or semi-metallurgical bond forms along with the mechanical engagement. While FIG. 2C shows locking feature 64 as a generally T shape, locking feature 64 can have other configurations as desired for particular embodiments. Investment cast sub-component 62 also has hollow feature 66, which is an opening that allows air, another fluid, or another part to go therein. Creation of hollow feature 66 in investment cast sub-component 62 would be difficult through the use of another process, such as die casting, but is a common practice in the investment casting process and can be accommodated in bondcasting process

10.

[0039] FIG. 3 is a cross-section of a finished apparatus constructed through bondcasting process 10 having another embodiment of a locking feature. FIG. 3 includes finished apparatus 159 having sand cast sub-component 160 and investment cast sub-component 162. Investment cast sub-component 162 has locking feature 164.

[0040] Investment cast sub-component 162 is formed through investment casting sub-process 12 of bondcasting process 10 and is configured to include locking feature 164, which is a groove into which sand cast sub-component 160 can extend (into which the liquefied sand casting material can flow and eventually solidify). Locking feature 164 can have a dovetail configuration in which the sides of locking feature 164 angle inward to prevent sand cast sub-component 160 from becoming separated from investment cast sub-component 162. During bondcasting process 10, investment cast sub-component 162 is placed and aligned within the mold such that investment cast sub-component 162 and locking feature 164 are adjacent to a void which is then filled with the second casting material to form sand cast sub-component 160. Sand cast sub-component 160 then solidifies adjacent to and within locking feature 164, producing a mechanical engagement. As mentioned above, the temperature of the sand casting material when introduced into the void can be varied to cause the surface of investment cast sub-component 162 to melt such that when second cast sub-component 160 and the surface of investment cast sub-component 162 solidify, a metallurgical or semi-metallurgical bond forms along with the mechanical engagement. While FIG. 3 shows locking feature 64 as one groove, locking feature 64 can have other configurations, such as multiple grooves or holes.

[0041] FIG. 4 is a cross-section of a finished apparatus constructed through bondcasting process 10 having a third embodiment of a locking feature. FIG. 4 includes finished apparatus 259 having sand cast sub-component 260 and investment cast sub-component 262. Investment cast sub-component 262 has locking feature 264.

[0042] Investment cast sub-component 262 is formed through investment casting sub-process 12 of bondcasting process 10 and is configured to include locking feature 264, which is a relatively wide projection that extends away from the body of investment cast sub-component 262 to provide an extension around which sand cast sub-component 260 can solidify to hold sand cast sub-component 260 and investment cast sub-component 262 stationary relative to one another. During bondcasting process 10, investment cast sub-component 262 is placed and aligned within the mold such that locking feature 264 extends into a void which is then filled with the second casting material to form sand cast sub-component 260 around locking feature 264, producing a mechanical engagement. In this configuration, sand would be in place in the space between sand cast sub-component 260 and investment cast sub-component 262 during some of the steps of sand casting sub-process 14 of bondcasting

process 10 to ensure that finished apparatus 259 includes such a space. As mentioned above, the temperature of the sand casting material when introduced into the void can be varied to cause the surface of locking feature 264 to melt such that when second cast sub-component 260 and locking feature 264 solidify, a metallurgical or semi-metallurgical bond forms along with the mechanical engagement. While FIG. 4 shows locking feature 64 as a generally dovetail shaped projection, locking feature 64 can have other configurations.

[0043] FIG. 5A is a cross-section of a portion of a turbine exhaust case constructed through bondcasting process 10, while FIG. 5B is a cross-section of a portion of the turbine exhaust case of FIG. 3A taken along section line B-B. Turbine exhaust case 359 includes first sand cast sub-component 360, a plurality of investment cast sub-components 362 (with each investment cast sub-component 362 having a plurality of locking features 364), and second sand cast sub-component 368.

[0044] Turbine exhaust case 359 is an exemplary embodiment of a device that can be constructed through bondcasting process 10. To construct turbine exhaust case 359, first the six investment cast sub-components 362 are made through investment casting sub-process 12. The six investment cast sub-components 362 are similar in shape and size and can be made at the same time (going through investment casting sub-process 12 together by being attached to a tree) or can be made independently by going through investment casting sub-process 12 individually. Because FIG. 5A shows a cross-section of turbine exhaust case 359, the hollow features within each investment cast sub-component 362 are not shown even though each investment cast sub-component 362 includes at least one hollow feature. Also, while FIG. 5A shows a finished apparatus that includes six investment cast sub-components 362, bondcasting process 10 can be used to construct a finished apparatus with more investment cast sub-components 362.

[0045] After the six investment cast sub-components 362 have been constructed, sand casting sub-process 14 of bondcasting process 10 is performed with a pattern being used to make a mold forming a void or multiple voids having the same dimensions of first sand cast sub-component 360, investment cast sub-components 362, and second sand cast sub-component 368. After the mold is made, investment cast sub-components 362 are placed in the mold and carefully aligned so that locking features 364 on each investment cast sub-component 362 are adjoining the voids that will eventually form first sand cast sub-component 360 and second sand cast sub-component 368.

[0046] Once investment cast sub-components 362 are aligned, the mold is completed by placing the two molds in the first and second molding boxes together. This creates the complete void having the same shape as first sand cast sub-component 360 and another complete void having the same shape as second cast sub-component 368. Then the two voids are filled with a sand casting

material. One material can be used to form first sand cast sub-component 360 and another material can be used to form second sand cast sub-component 368 or the same material can be used to form both. The sand casting materials completely fill the voids such that locking features 364, which project into the voids, are surrounded by the sand casting material. Finally, the sand casting materials are solidified to create first sand cast sub-component 360 adjoining the outer side of investment cast sub-components 362 and second sand cast sub-component 368 adjoining the inner side of investment cast sub-components 362. Once the molds are removed and final finishing is performed, turbine exhaust case 359 is a finished apparatus with sub-components that are of different materials.

[0047] The sub-components are prevented from movement relative to one another through locking features 364, with an exemplary embodiment shown in FIG. 5B as a dovetail configuration that prevents first sand cast sub-component 360 from separating from investment cast sub-component 362 (the structure forms a geometrical configuration that does not allow sand cast sub-component 360 to be pulled away from investment cast sub-component 362; this configuration is known as a mechanical engagement). While FIG. 5B shows locking feature 364 as a projection having a dovetail configuration, locking feature 364 can have various other configurations that prevent the sub-components from moving relative to one another, with some examples shown in previous figures.

[0048] As mentioned above, bondcasting process 10 includes investment casting sub-process 12 and sand casting sub-process 14, with new steps incorporated therein that are necessary to manufacture a finished apparatus that has sub-components constructed from multiple materials. Bondcasting process 10 can omit investment casting sub-process 12 and can include another sub-process suited to produce the first sub-component. Bondcasting process 10 does not require the sub-components (the investment cast sub-components and the sand cast sub-components) to be welded, riveted, bolted, or otherwise fastened to one another after bondcasting process 10 is complete because the sub-components will be locked together through mechanical engagements. Bondcasting process 10 can be performed even if a sub-component is constructed from a material that has a relatively high melting point, like a superalloy (such as a nickel based superalloy), and/or if a sub-component requires hollow features or an opening within the sub-component. Bondcasting process 10 can also be performed even if a sub-component is too large to be efficiently constructed through another casting process, such as die casting. Additionally, bondcasting process 10 is flexible and allows for easy adjustment to produce sub-components that are closer to the desired configuration because the pattern and molds used to make the finished apparatus can be formed and altered more easily than other processes. This flexibility is important when

multiple sub-components are being constructed together to form a finished apparatus.

Discussion of Possible Embodiments

[0049] The following are non-exclusive descriptions of possible embodiments of the present invention.

[0050] A method of manufacturing an apparatus includes providing a first sub-component having a locking feature with the first sub-component being constructed from a superalloy, placing the first sub-component into a void in sand in a sand molding box with the void having a first portion shaped like the first sub-component and a second portion shaped like a second sub-component and the first sub-component sitting in the void such that the locking feature is adjoining the second portion and the second portion is unoccupied by the first sub-component, introducing a second material in a fluidic state into the second portion so that the second material is adjacent to at least a part of the locking feature, and allowing the second material to solidify to form the second sub-component adjoining the locking feature.

[0051] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations, steps, and/or additional components:

[0052] The step of placing the first sub-component into the void in the sand casting mold includes molding part of the first portion of the void and part of the second portion of the void in a first sand molding box through the use of a first pattern, placing at least a part of the first sub-component into the part of the first portion of the void, molding a remaining part of the first portion of the void and a remaining part of the second portion of the void in a second sand molding box through the use of a second pattern, and placing the second sand molding box adjacent to the first sand molding box.

[0053] The part of the first portion in the first sand molding box and the remaining part of the first portion in the second sand molding box form the void that has the same dimensions as the first sub-component such that when at least a part of the first sub-component is placed into the part of the first portion of the first half of the sand molding box the sand in the first half of the sand molding box is undisturbed and when the remaining part of the first portion in the second half of the sand molding box is placed adjacent to the first half of the sand molding box the sand in the second half of the sand molding box is undisturbed.

[0054] The first sub-component is made up of a plurality of pieces with each piece being similarly shaped and unattached to other pieces of the first sub-component.

[0055] Aligning the plurality of pieces in the first portion of the void.

[0056] The second sub-component has an annular shape and the plurality of pieces of the first sub-component are arranged radially within the second sub-component.

[0057] The locking feature is a projection that extends into the second portion such that the second sub-component solidifies around the locking feature.

[0058] The first sub-component includes at least one hollow feature.

[0059] The melting temperature of the first material is higher than the melting temperature of the second material.

[0060] The first component is constructed using investment casting.

[0061] Performing final finishing on the first sub-component and the second sub-component.

[0062] A method of making an apparatus constructed from at least two different materials includes investment casting a first sub-component constructed from a first material with the first sub-component having a locking feature, placing a first pattern in sand to create a first sand casting mold, placing a second pattern in sand to create a second sand casting mold, removing the first pattern and the second pattern, positioning the first sub-component in a first impression in the first sand casting mold with the first impression being sized to house at least a portion of the first sub-component and the first sub-component being positioned so that the locking feature is adjoining a second impression in the first sand casting mold that has the same dimensions as at least a portion of a second sub-component, assembling the first sand casting mold and the second sand casting mold so that the first sub-component is within a first cavity having the same dimensions as the first sub-component and a second cavity having the same dimensions as the second sub-component is formed adjacent to the locking feature, introducing a second material in a fluidic state into the second cavity to form the second sub-component, and solidifying the second material within the second cavity adjoining the locking feature.

[0063] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations, steps, and/or additional components:

[0064] Removing the first sand casting mold and the second sand casting mold from around the first sub-component and the second sub-component.

[0065] The second sub-component solidifies around the locking feature.

[0066] The first sub-component includes at least one hollow feature.

[0067] A method of forming a component having a plurality of parts constructed from at least two different materials includes forming a first part made from a first material, placing a sandcasting pattern in a sand molding box, filling the sand molding box with sand, removing the sandcasting pattern from the sand molding box, placing the first part in a first portion of a void in the sand with the void formed by the removal of the sandcasting pattern, filling a remaining area of the void with a second material, and allowing the second material to solidify to form a second part.

[0068] The method of the preceding paragraph can optionally include, additionally and/or alternatively, any one or more of the following features, configurations, steps, and/or additional components:

[0069] Forming a third part made from a third material and placing the third part in a second portion of the void in the sand.

[0070] The first part and the third part are formed using investment casting.

[0071] The first part is a plurality of similarly shaped pieces.

[0072] The first part is made from a high temperature alloy.

[0073] Any relative terms or terms of degree used herein; such as "substantially," "essentially," "generally," "approximately," and the like; should be interpreted in accordance with and subject to any applicable definitions or limits expressly stated herein. In all instances, any relative terms or terms of degree used herein should be interpreted to broadly encompass any relevant disclosed embodiments as well as such ranges or variations as would be understood by a person of ordinary skill in the art in view of the entirety of the present disclosure, such as to encompass ordinary manufacturing tolerance variations, incidental alignment variations, alignment or shape variations induced by thermal, rotational, or vibrational operations, and the like.

[0074] 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 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 manufacturing an apparatus comprising:

providing a first sub-component (62) having a locking feature (64), the first sub-component being constructed from a superalloy;

placing the first sub-component (62) into a void (53) in sand in a sand molding box, the void (53) having a first portion shaped like the first sub-component (62) and a second portion shaped like a second sub-component (60) with the first sub-component (62) sitting in the void (53) such that the locking feature (64) is adjoining the second portion and the second portion is unoccupied by the first sub-component (62);

introducing a second material in a fluidic state

into the second portion so that the second material is adjacent to at least a part of the locking feature (64); and

solidifying the second material to form the second sub-component (62) adjoining the locking feature (64).

2. The method of claim 1, the step of placing the first sub-component (62) into the void (53) in the sand casting mold comprising:

molding part of the first portion of the void and part of the second portion of the void in a first sand molding box through the use of a first pattern;

placing at least a part of the first sub-component into the part of the first portion of the void;

molding a remaining part of the first portion of the void and a remaining part of the second portion of the void in a second sand molding box through the use of a second pattern; and

placing the second sand molding box adjacent to the first sand molding box.

3. The method of claim 2, wherein the part of the first portion in the first sand molding box and the remaining part of the first portion in the second sand molding box form the void that has the same dimensions as the first sub-component (62) such that when at least a part of the first sub-component is placed into the part of the first portion of the first half of the sand molding box the sand in the first half of the sand molding box is undisturbed and when the remaining part of the first portion in the second half of the sand molding box is placed adjacent to the first half of the sand molding box the sand in the second half of the sand molding box is undisturbed.

4. The method of any preceding claim, wherein the first sub-component (62) is made up of a plurality of pieces with each piece being similarly shaped and unattached to other pieces of the first sub-component.

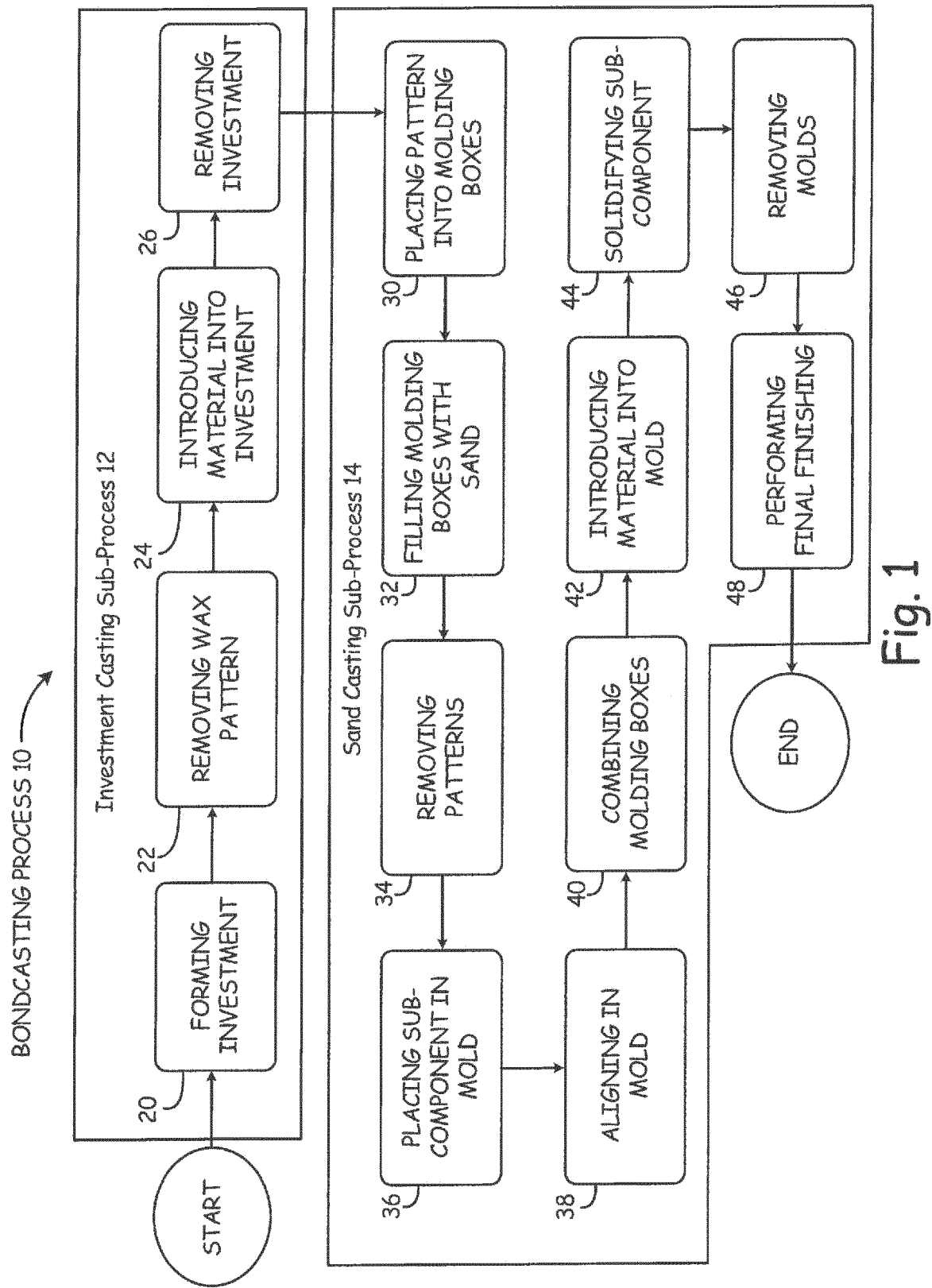
5. The method of claim 4, further comprising:

aligning the plurality of pieces in the first portion of the void (53).

6. The method of claims 4 or 5, wherein the second sub-component (60) has an annular shape and the plurality of pieces of the first sub-component (62) are arranged radially within the second sub-component (60).

7. The method of any preceding claim, wherein the locking feature (64) is a projection that extends into the second portion such that the second sub-component (60) solidifies around the locking feature (64).

8. The method of any preceding claim, wherein the first sub-component (62) includes at least one hollow feature.
9. The method of any preceding claim, wherein the melting temperature of the first material is higher than the melting temperature of the second material, and preferably wherein the first sub-component is constructed using investment casting.
10. The method of any preceding claim, further comprising:
- performing final finishing on the first sub-component (62) and the second sub-component (60).
11. A method of making an apparatus constructed from at least two different materials, the method comprising:
- investment casting a first sub-component (62) constructed from a first material, the first sub-component having a locking feature (64);
- placing a first pattern in sand to create a first sand casting mold;
- placing a second pattern in sand to create a second sand casting mold;
- removing the first pattern and the second pattern;
- positioning the first sub-component (62) in a first impression in the first sand casting mold, the first impression being sized to house at least a portion of the first sub-component, the first sub-component being positioned so that the locking feature (64) is adjoining a second impression in the first sand casting mold that has the same dimensions as at least a portion of a second sub-component (60);
- assembling the first sand casting mold and the second sand casting mold so that the first sub-component is within a first cavity having the same dimensions as the first sub-component and a second cavity having the same dimensions as the second sub-component is formed adjacent to the locking feature (64);
- introducing a second material in a fluidic state into the second cavity to form the second sub-component (60); and
- allowing the second material to solidify within the second cavity adjoining the locking feature (64).
12. The method of claim 11, further comprising:
- removing the first sand casting mold and the second sand casting mold from around the first sub-component (62) and the second sub-component (60), and preferably wherein the second sub-component (60) solidifies around the locking feature (64), and more preferably wherein the first sub-component (62) includes at least one hollow feature.
13. A method of forming a component having a plurality of parts constructed from at least two different materials, the method comprising:
- forming a first part made from a first material;
- placing a sandcasting pattern in a sand molding box;
- filling the sand molding box with sand;
- removing the sandcasting pattern from the sand molding box;
- placing the first part in a first portion of a void in the sand, the void formed by the removal of the sandcasting pattern;
- filling a remaining area of the void with a second material; and
- allowing the second material to solidify to form a second part.
14. The method of claim 13, further comprising:
- forming a third part made from a third material; and
- placing the third part in a second portion of the void in the sand, and preferably wherein the first part and the third part are formed using investment casting.
15. The method of claims 13 or 14, wherein the first part is a plurality of similarly shaped pieces, and preferably wherein the first part is made from a high temperature alloy.



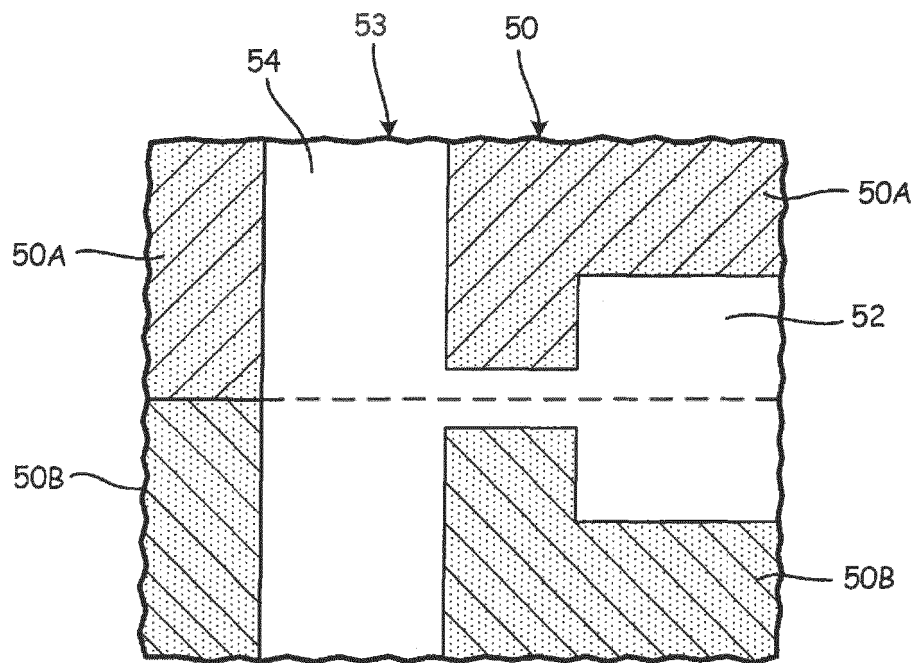


Fig. 2A

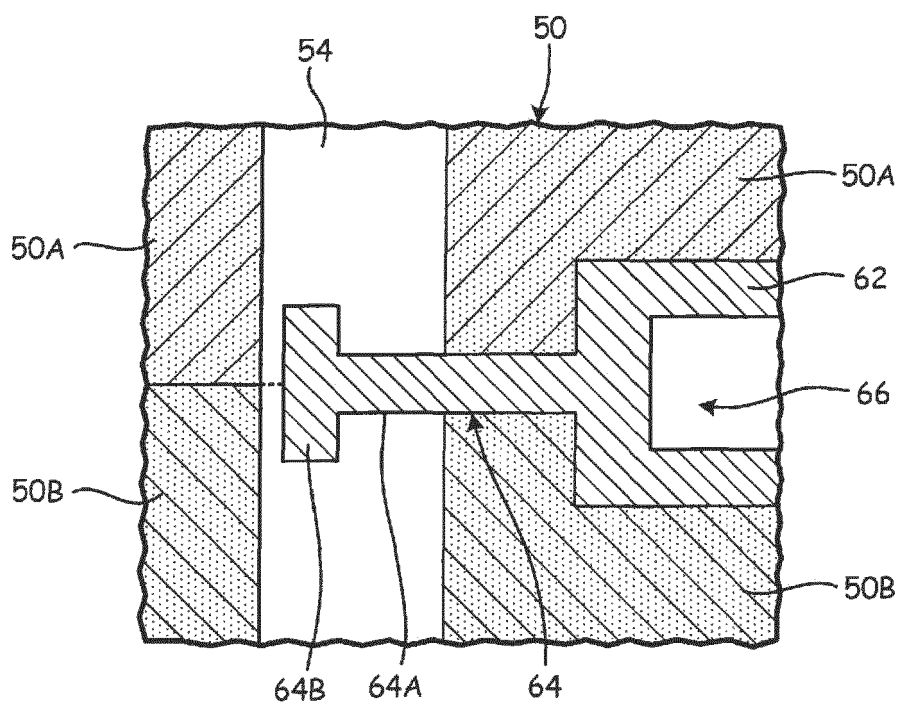


Fig. 2B

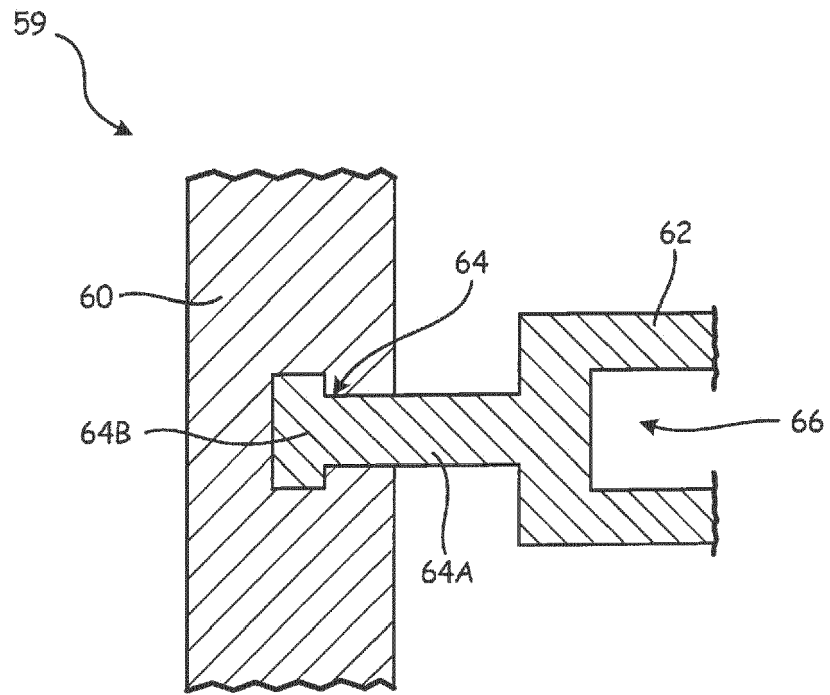


Fig. 2C

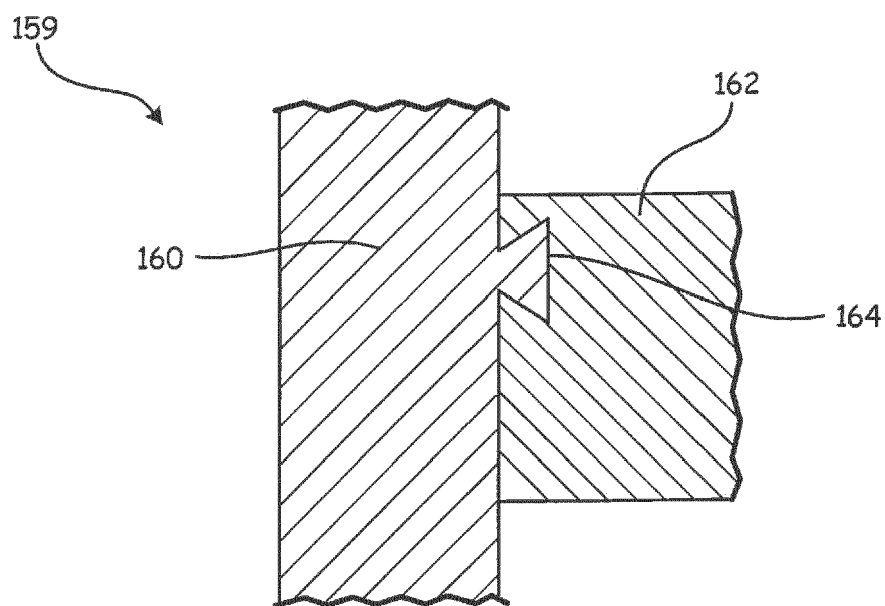


Fig. 3

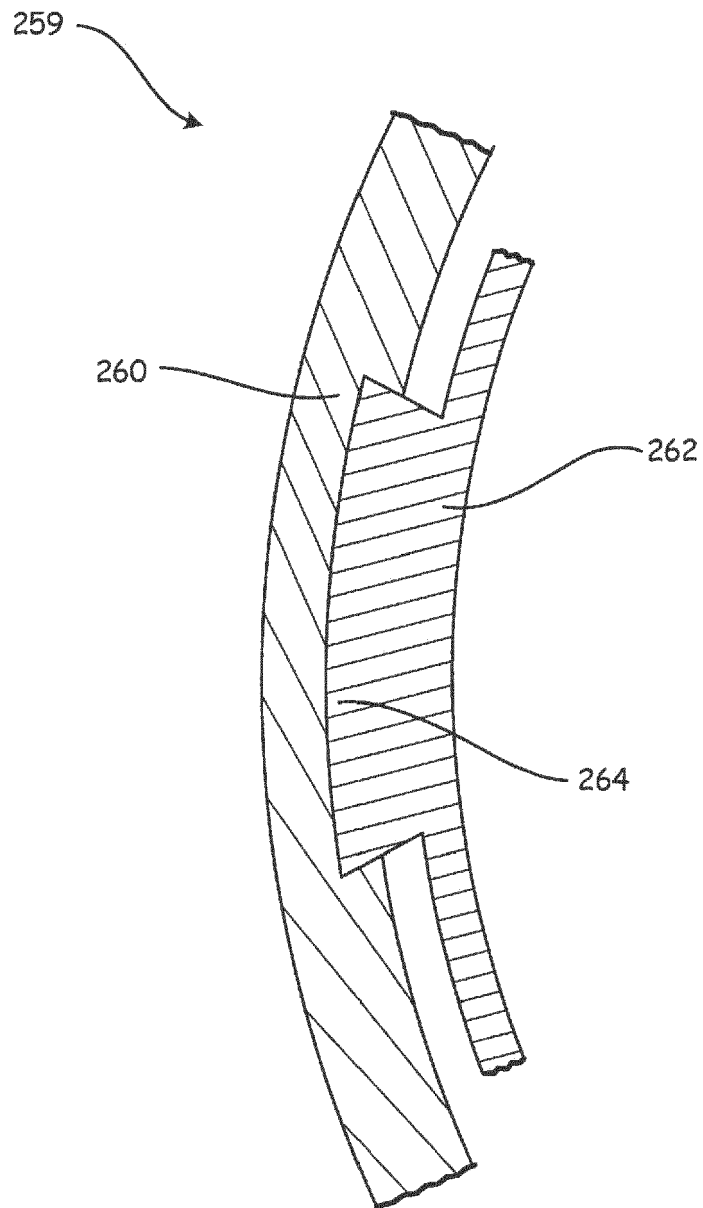


Fig. 4

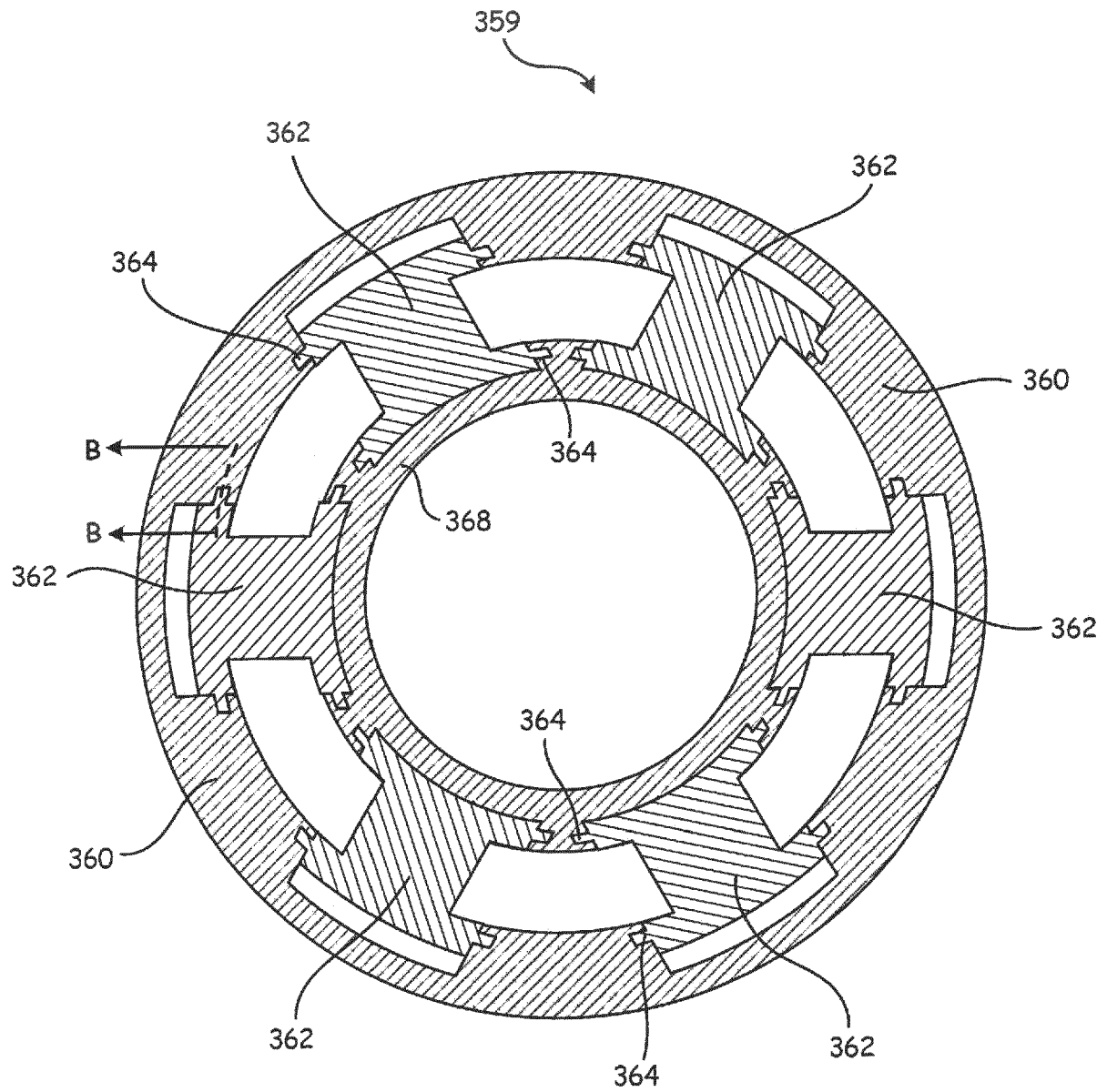


Fig. 5A

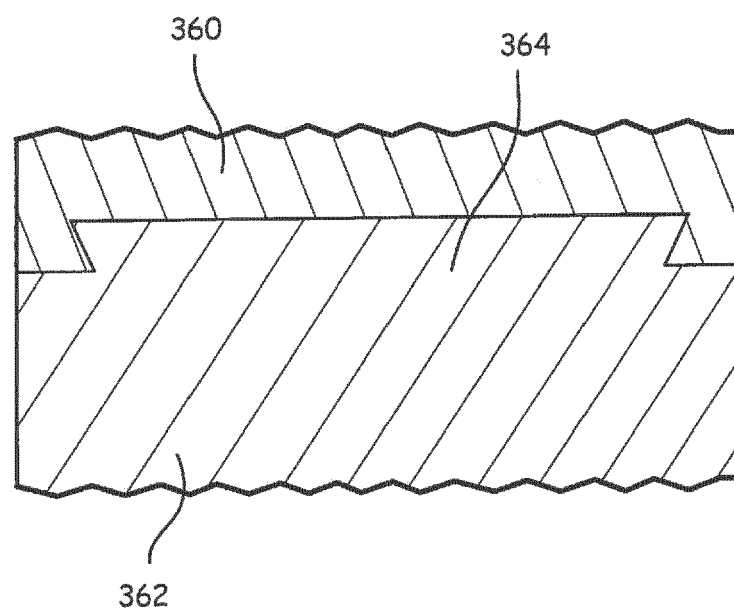


Fig. 5B