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(54) **Process for making a turbine wheel and shaft assembly**

(57) A process for making a turbine rotor includes steps of providing a shaft made of a first metal composition and having an integral pin projecting axially therefrom, providing a mold that defines a cavity for investment casting a turbine wheel, disposing the pin within the cavity of the mold, pre-heating the mold and the pin to a mold temperature, pouring a molten second metal composition into the cavity of the pre-heated mold such that the molten second metal composition envelopes the pin within the cavity, and controlling the process so that the pin acts as a chill member causing the second metal composition around the chill member to solidify with a finer equiaxed grain structure than would be the case without the chill member. The turbine wheel is joined to the shaft via the casting of the turbine wheel about the pin.

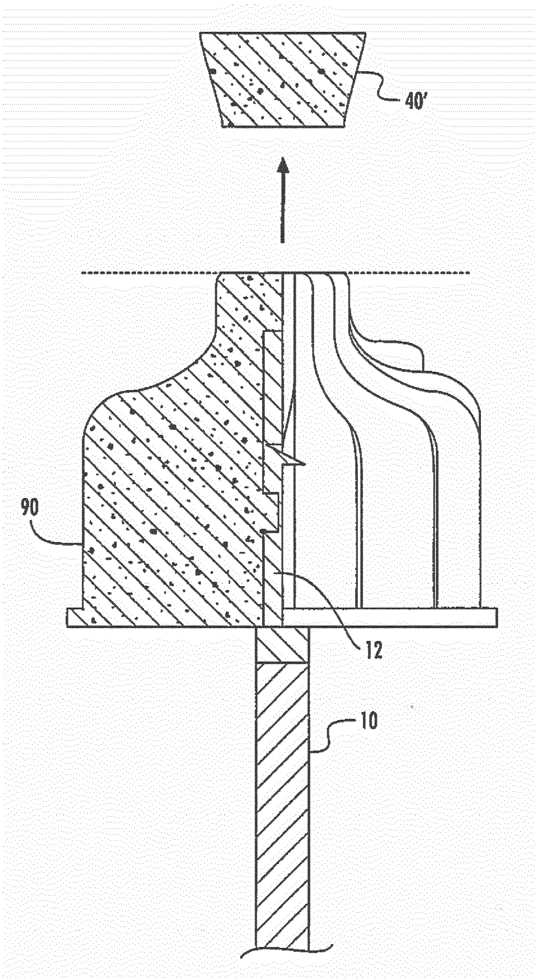

FIG. 4

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Description

BACKGROUND OF THE INVENTION

[0001] The present disclosure relates generally to the manufacture of turbine wheels, and more particularly relates to the casting of turbine wheels.

[0002] Turbine wheels in turbomachinery (e.g., gas turbine engines, turbochargers, and the like) operate in extremely challenging environments. The high temperature of the gases passing through the wheel, combined with the high rotational speeds typically experienced, result in severe testing of the strength and/or fatigue-resistance limits of the turbine wheel and shaft assembly. At the speeds and temperatures reached by turbocharger turbine wheels, for instance, the weld joint typically used for joining the shaft to the turbine wheel can be severely tested. Weld joint failures can sometimes occur. The present disclosure concerns a process for making a turbine rotor (i.e., turbine wheel and shaft assembly) that does not rely upon a weld joint.

BRIEF SUMMARY OF THE DISCLOSURE

[0003] The present disclosure describes a process for making a turbine rotor, comprising steps of:

providing a shaft made of a first metal composition, one end of the shaft having an integral pin projecting axially therefrom;
providing a mold that defines a cavity into which a molten second metal composition is to be poured for investment casting a turbine wheel, the cavity being configured for defining a hub portion of the turbine wheel and for defining blades extending from the hub portion;
disposing the pin within the cavity of the mold;
pre-heating the mold and the pin to a mold temperature within a range between a predefined minimum mold temperature and a predefined maximum mold temperature;
pouring the molten second metal composition into the cavity of the pre-heated mold such that the molten second metal composition envelopes the pin within the cavity, wherein the second metal composition differs from the first metal composition; and
controlling the process so that the molten second metal composition at the time of pouring is at a metal temperature exceeding the maximum mold temperature, the pin thus acting as a chill member causing the second metal composition around the chill member to solidify with a finer equiaxed grain structure than would be the case without the chill member.

[0004] In accordance with the invention, the turbine wheel is joined to the shaft via the casting of the turbine wheel about the pin. The typically used weld joint between the wheel and shaft thus is not required.

[0005] In one embodiment, the pin is disposed in a region of the cavity that is configured for defining the hub portion of the turbine wheel.

[0006] The process can further comprise the step, prior to the disposing step, of treating an outer surface of the pin to remove any oxide layer and foreign substances thereon.

[0007] In one embodiment, the pre-heating step comprises providing a furnace and disposing the mold and the pin within the furnace, and operating the furnace so that an internal temperature within the furnace is within said range.

[0008] Preferably the predefined maximum mold temperature is selected to be below the solidus temperature for the second metal composition.

[0009] The process can be used with various metal compositions for the wheel (i.e., the second metal composition). In one embodiment, the second metal composition is selected from the group consisting of nickel-based superalloys and cobalt alloys.

[0010] In accordance with a particular embodiment described herein, the second metal composition is selected to be a nickel-based superalloy comprising (in wt%):

chromium 8-15;
molybdenum 0-5.5;
niobium + tantalum 1-3;
aluminum 5.4-6.5;
titanium 0-1.25;
carbon 0-0.2;
boron 0-0.1;
zirconium 0-0.1;
silicon 0-1;
manganese 0-0.1;
iron 0-5;
unavoidable impurities; and
nickel balance.

[0011] In another embodiment, the second metal composition is selected to be a cobalt alloy comprising (in wt%):

chromium 25-30;
molybdenum 0-1;
tungsten 2-15;
carbon 0.25-3.3;
iron 0-3;
nickel 0-3;
silicon 0-2;
manganese 0-1;
unavoidable impurities; and
cobalt balance.

[0012] The first metal composition of the shaft can be a steel. Preferably the pin includes an outer coating of nickel.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0013] Having thus described the disclosure in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a perspective view of a shaft having an integral pin projecting axially therefrom, in accordance with an embodiment of the invention;

FIG. 2A depicts the shaft of FIG. 1 after having been affixed within a back disc formed of a low-melting polymer composition such as wax or thermoplastic;

FIG. 2B illustrates a step of affixing the assembly of FIG. 2A into a positive wheel pattern and attaching a feed member onto the wheel pattern, the wheel pattern and feed member constituting a low-melting polymer composition;

FIG. 2C shows the completed assembly of FIG. 2B;

FIG. 3A illustrates a series of steps for forming a ceramic mold around the wheel portion of the assembly of FIG. 2C;

FIG. 3B depicts a process of melting away the wheel pattern and feed member from the mold, so as to leave a ceramic mold whose internal cavity is configured as a negative of the wheel pattern;

FIG. 3C depicts a process of pouring a molten metal composition, having the same composition as that of the seed member, into the cavity of the mold, followed by cooling to solidify the wheel, and finally removing the ceramic mold to leave a wheel casting attached to the shaft; and

FIG. 4 illustrates removal of a portion of metal corresponding to the feed member.

DETAILED DESCRIPTION OF THE DRAWINGS

[0014] The invention now will be described more fully hereinafter with reference to the accompanying drawings in which some but not all possible embodiments are shown. Indeed, the invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

[0015] As noted, the process for making a turbine rotor in accordance with the invention generally entails using a pin that projects axially from a turbine shaft to act as a chill pin during the investment casing of the wheel, so as to produce a finer equiaxed grain structure in the wheel hub than would be the case without the chill pin. FIG. 1 shows such a shaft **10** in accordance with one embodiment of the invention, in which the shaft include a pin **12** formed integrally with the shaft and projecting axially from the shaft. The particular configuration of the pin **12** in FIG. 1 is merely exemplary, and the invention is not limited to any particular configuration. The investment-casting process in accordance with the present disclosure generally entails casting the wheel around the pin **12** and controlling the process in such a way that the pin acts as a chill pin. As the metal solidifies, the equiaxed grain structure in the metal of the wheel is caused to be finer because of the presence of the chill pin.

[0016] FIGS. 2A through 2C illustrate the construction of a wheel pattern assembly **50** that will be used for forming a ceramic mold for the wheel to be cast. The wheel pattern assembly **50** includes a back disc **20** formed of a low-melting polymer material such as wax or thermoplastic. The wheel pattern assembly further includes a positive wheel pattern **30** having a configuration corresponding to the wheel to be cast, and a feed member **40,** each formed of a low-melting polymer material. The wheel pattern **30** includes a central bore for receiving the pin **12** therein. The feed member **40** is affixed to the end of the wheel pattern **30** opposite from the back disc **20,** and is provided for forming a feed portion (essentially a funnel) in the mold through which the molten metal composition will be poured into the mold cavity.

[0017] The wheel pattern assembly **50** of FIG. 2C is then used for forming a ceramic mold. FIG. 3A illustrates the process for building up the ceramic mold. The wheel pattern assembly **50** is dipped a number of times into a ceramic slurry, and after each dipping the layer of slurry on the assembly is dried. In this manner, a number of layers of the ceramic material are deposited successively until the desired thickness of the mold is obtained. Typically five to 10 layers are employed.

[0018] Next, the low-melting back disc **20,** wheel pattern **30,** and feed member **40** are melted out of the ceramic mold as shown in FIG. 3B, leaving a ceramic mold **60** that is ready for casting. As shown, the pin **12** is disposed within the cavity of the mold **60.**

[0019] To cast a turbine wheel, the mold **60** with the embedded pin **12** is pre-heated by a suitable heating device **70** as shown at the left in FIG. 3C, so that the mold **60** and pin **12** are at a mold temperature falling within a predetermined range between a minimum mold temperature and a maximum mold temperature. The heating device **70** can be, for example, a furnace that the mold **60** is disposed within during the casting process. The mold temperature range is selected such that the maximum mold temperature is below the solidus temperature for the molten metal composition that will be poured into the mold. While the mold and seed member are thus heated to the desired temperature, molten metal **80** is poured into the mold until the mold is substantially full (middle of FIG. 3C). The temperature of the molten metal being poured is higher than the predetermined maximum mold temperature. Once the pouring is completed, the heating is discontinued and the metal composition is allowed or caused to cool and solidify. After the metal is cool, the ceramic mold **60** is broken away, leaving a wheel casting **90** affixed to the shaft **10** via the embedded pin **12** (right side of FIG. 3C).

[0020] Finally, as illustrated in FIG. 4, a feed portion **40'** corresponding to the feed member **40** is severed from the wheel proper. The wheel casting **90** is then ready for final finishing operations.

[0021] In summary, the process in accordance with the invention allows a fine-grain structure in the thick hub region of the turbine wheel to be achieved via the assistance of the pin **12,** which acts as a chill pin positioned at the center of the high-volume mass and able to absorb and dissipate heat via conduction along its length.

[0022] The pin during the casting process is well below the solidus temperature of the liquid metal; e.g., in the case of a nickel-based superalloy such as Inconel 713C the pin can be at temperature of about 1050° C to 1150° C (1920° F to 2100° F), while the solidus temperature of Inconel 713C is about 1260° C (2300° F).

[0023] The process generally as described above can be used for casting turbine wheels from various metal compositions. It is expected that the process is applicable to at least nickel-based superalloys and cobalt alloys.

[0024] In a particular embodiment, the metal composition for the wheel is selected to be a nickel-based superalloy comprising (in wt%):

chromium 8-15;
molybdenum 0-5.5;
niobium + tantalum 1-3;
aluminum 5.4-6.5;
titanium 0-1.25;
carbon 0-0.2;
boron 0-0.1;
zirconium 0-0.1;
silicon 0-1;
manganese 0-0.1;
iron 0-5;
unavoidable impurities; and
nickel balance.

[0025] In another embodiment, the metal composition for the wheel is selected to be a cobalt alloy comprising (in wt%):

chromium 25-30;
molybdenum 0-1;
tungsten 2-15;
carbon 0.25-3.3;
iron 0-3;
nickel 0-3;
silicon 0-2;
manganese 0-1;
unavoidable impurities; and
cobalt balance.

[0026] The first metal composition of the shaft can be a steel. Preferably the pin **12** includes an outer coating **14** of nickel (also known as a "nickel strike"), as depicted in FIGS. 3A and 3B, for improving adhesion of the wheel metal to the steel pin **12.**

[0027] As previously noted, a key aspect of the investment casting process is pre-heating the mold and pin to a mold temperature falling within a range between a predetermined minimum mold temperature and a predetermined maximum mold temperature. In the case of a nickel-based superalloy such as Inconel 713C, for instance, the mold and pin can be pre-heated to about 1050° C to 1150° C (1920° F to 2100° F), which is well below Inconel 713C's solidus temperature of approximately 1260° C (2300° F).

[0028] Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

Claims

1. A process for making a turbine rotor, comprising steps of:

providing a shaft made of a first metal composition, one end of the shaft having an integral pin projecting axially therefrom;
providing a mold that defines a cavity into which a molten second metal composition is to be poured for investment casting a turbine wheel, the cavity being configured for defining a hub portion of the turbine wheel and for defining blades extending from the hub portion;
disposing the pin within the cavity of the mold;
pre-heating the mold and the pin to a mold temperature within a range between a predefined minimum mold temperature and a predefined maximum mold temperature;
pouring the molten second metal composition into the cavity of the pre-heated mold such that the molten second metal composition envelopes the pin within the cavity, wherein the second metal composition differs from the first metal composition; and
controlling the process so that the molten second metal composition at the time of pouring is

at a metal temperature exceeding the maximum mold temperature, the pin thus acting as a chill member causing the second metal composition around the chill member to solidify with a finer equiaxed grain structure than would be the case without the chill member,
the turbine wheel being joined to the shaft via the casting of the turbine wheel about the pin.

2. The process of claim 1, wherein the pin is disposed in a region of the cavity that is configured for defining the hub portion of the turbine wheel.

3. The process of claim 1, further comprising, prior to the disposing step, treating an outer surface of the pin to remove any oxide layer and foreign substances thereon.

4. The process of claim 1, wherein the pre-heating step comprises providing a furnace and disposing the mold and the pin within the furnace, and operating the furnace so that an internal temperature within the furnace is within said range.

5. The process of claim 4, wherein the predefined maximum mold temperature is selected to be below the solidus temperature for the second metal composition.

6. The process of claim 1, wherein the second metal composition is selected from the group consisting of nickel-based superalloys and cobalt alloys.

7. The process of claim 6, wherein the second metal composition is selected to be a nickel-based superalloy comprising (in wt%):

chromium 8-15;
molybdenum 0-5.5;
niobium + tantalum 1-3;
aluminum 5.4-6.5;
titanium 0-1.25;
carbon 0-0.2;
boron 0-0.1;
zirconium 0-0.1;
silicon 0-1;
manganese 0-0.1;
iron 0-5;
unavoidable impurities; and
nickel balance.

8. The process of claim 7, wherein the second metal composition is selected to be a cobalt alloy comprising (in wt%):

chromium 25-30;
molybdenum 0-1;
tungsten 2-15;
carbon 0.25-3.3;
iron 0-3;
nickel 0-3;
silicon 0-2;
manganese 0-1;
unavoidable impurities; and
cobalt balance.

9. The process of claim 7, wherein the first metal composition of the shaft is a steel.

10. The process of claim 9, wherein the pin includes an outer coating of nickel.

FIG. 1

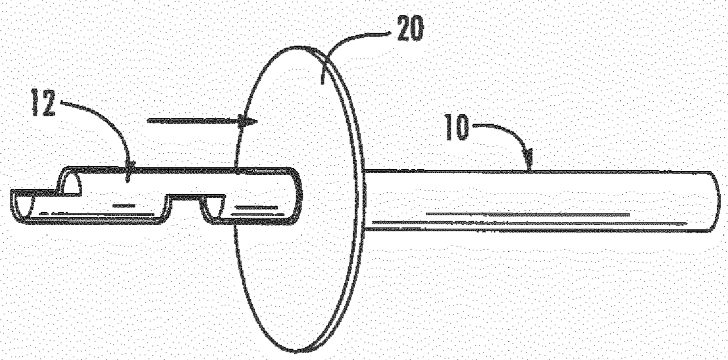

FIG. 2A

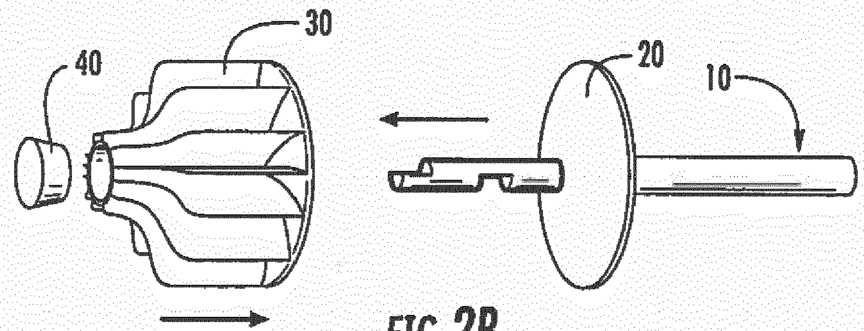

FIG. 2B

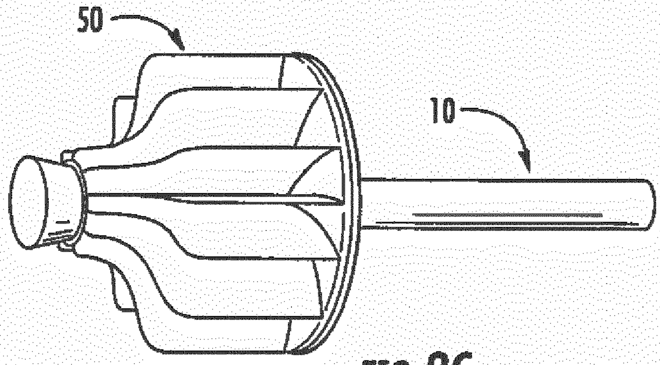

FIG. 2C

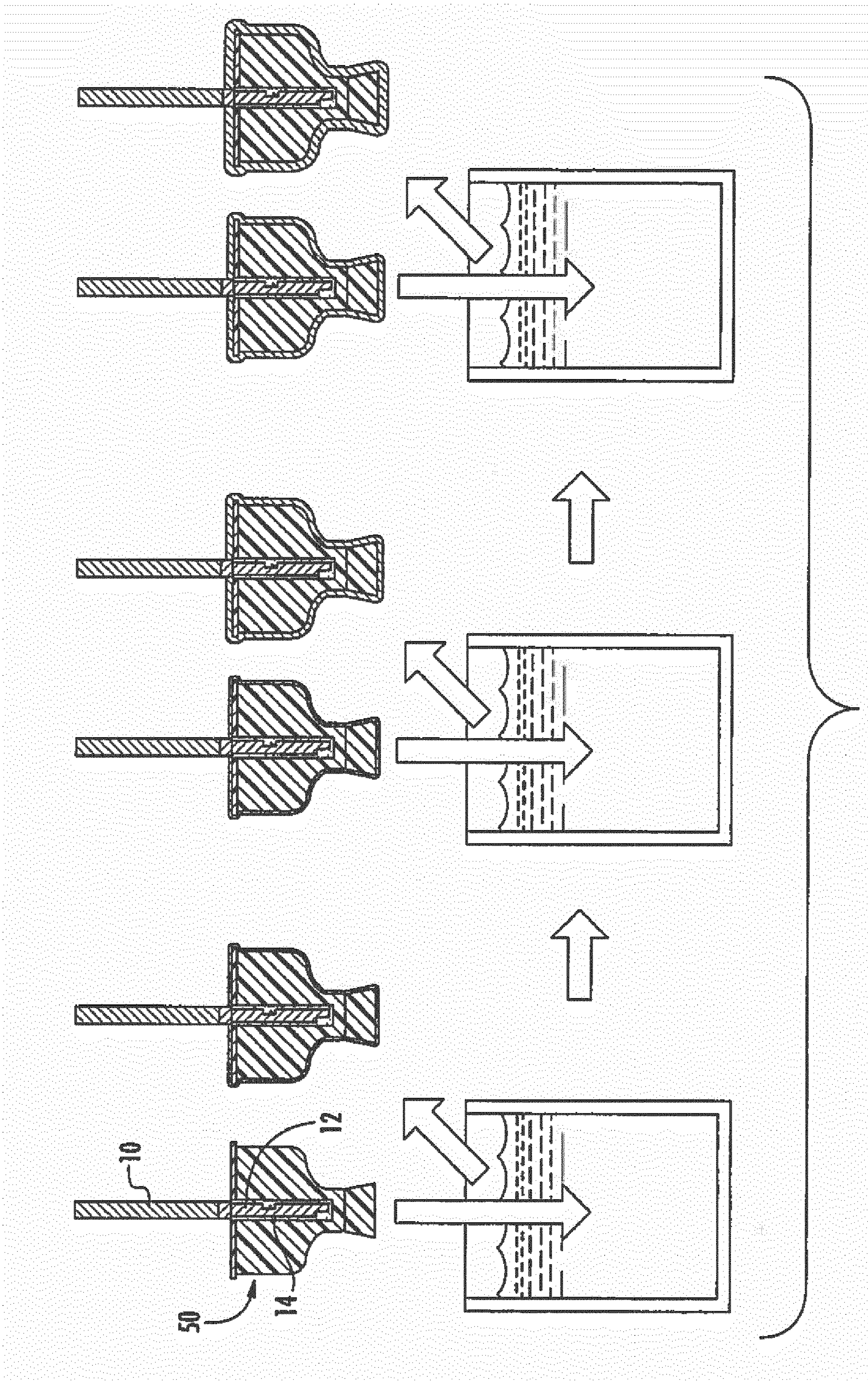

FIG. 3A

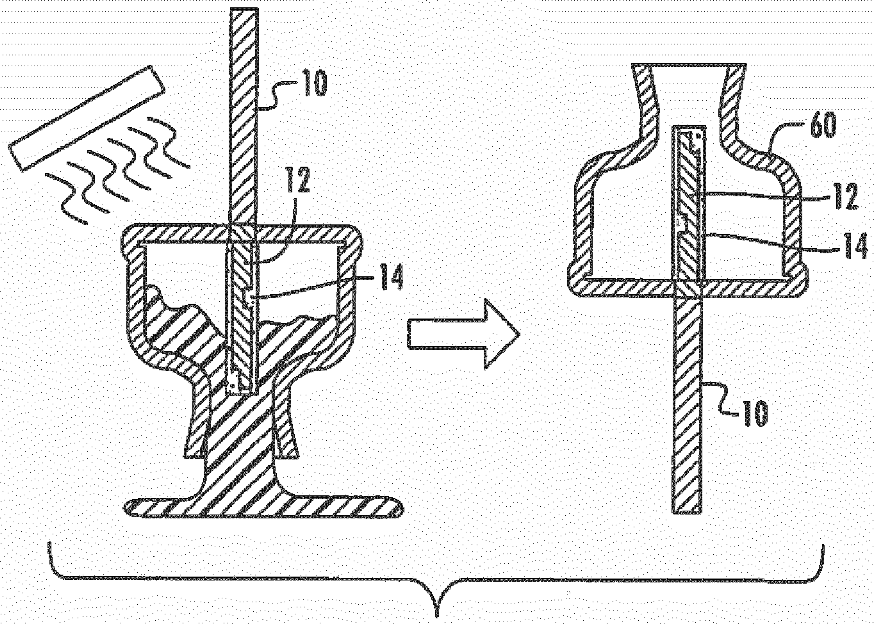

FIG. 3B

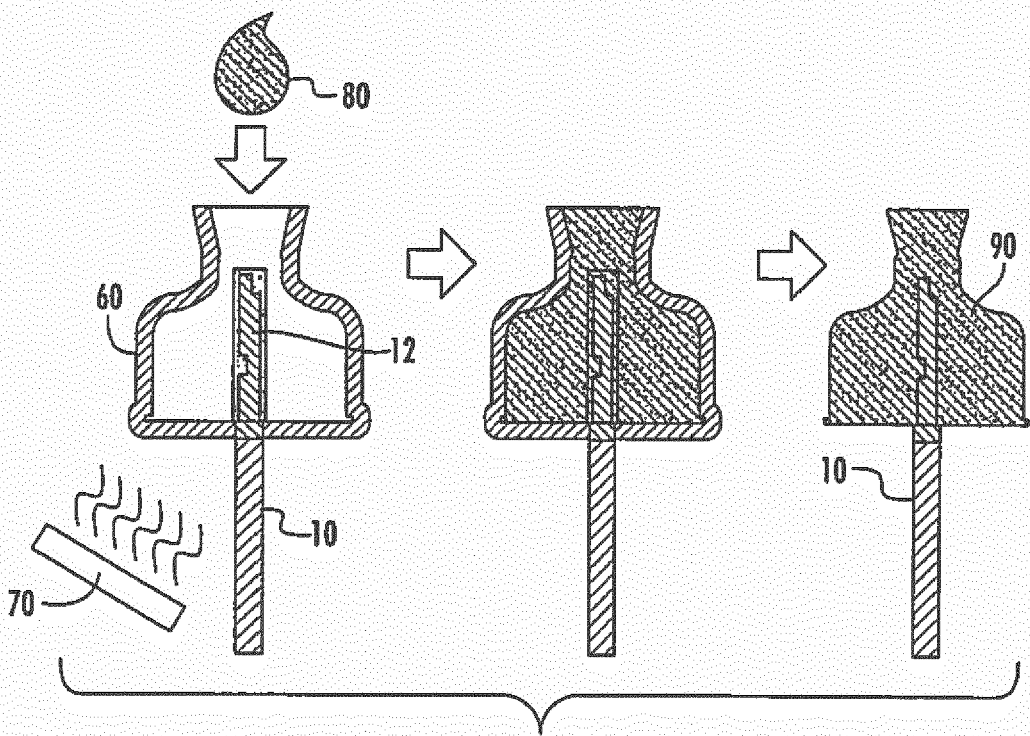

FIG. 3C

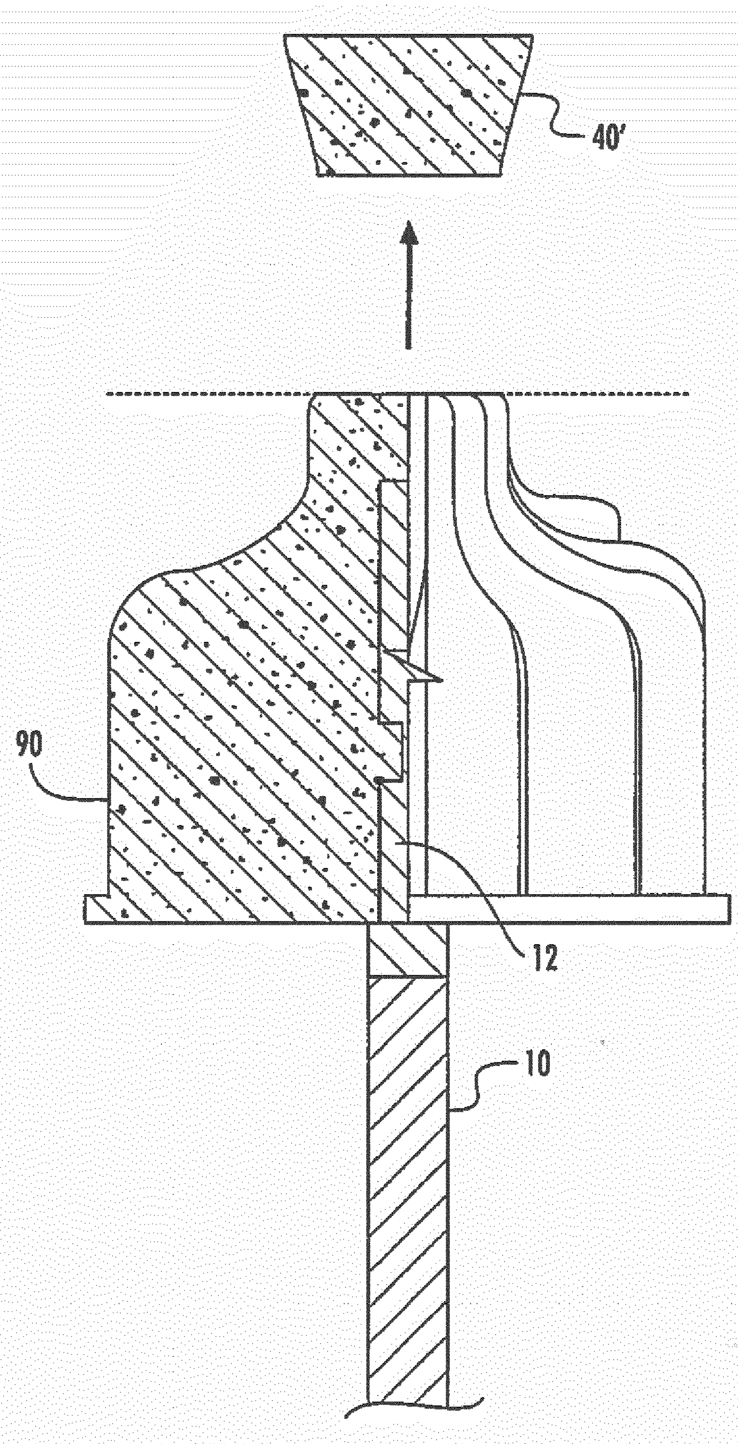

FIG. 4