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(54) **Methods for centrifugally casting highly reactive titanium metals**

(57) Methods for centrifugally casting a highly reactive titanium metal involving providing a cold wall induction crucible having a plurality of induction coils and a removable bottom plate, using a power source to heat a titanium metal charge in the induction crucible to obtain a molten metal, preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine, positioning the centrifugal casting machine having the secondary crucible beneath the induction crucible, withdrawing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten metal to fall from the induction crucible into the secondary crucible, and accelerating the secondary crucible to centrifugally force the molten metal into a casting mold to produce a cast component.

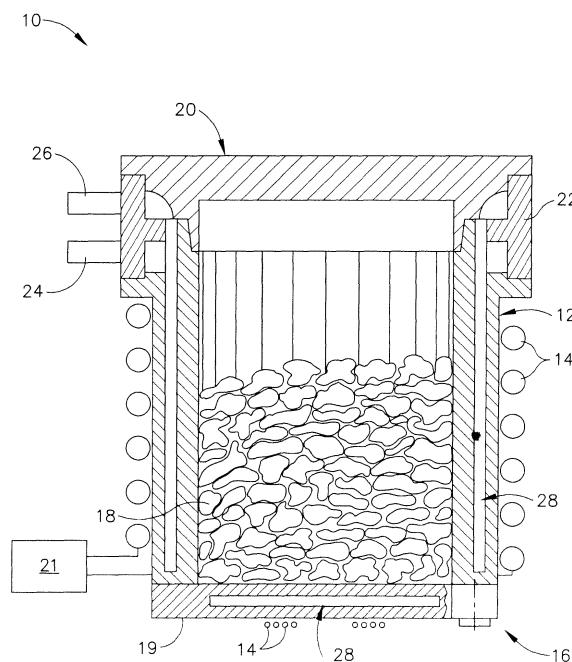


FIG. 1

## Description

### TECHNICAL FIELD

**[0001]** Embodiments described herein generally relate to methods for centrifugally casting highly reactive metals. More particularly, embodiments herein generally describe methods for centrifugally casting highly reactive titanium alloys, and in particular, titanium aluminide alloys.

### BACKGROUND OF THE INVENTION

**[0002]** Turbine engine designers are continuously looking for new materials with improved properties for reducing engine weight and obtaining higher engine operating temperatures. Titanium alloys (Ti alloys), and in particular, titanium aluminide based alloys (TiAl alloys), possess a promising combination of low-temperature mechanical properties, such as room temperature ductility and toughness, as well as high intermediate temperature strength and creep resistance. For these reasons, TiAl alloys have the potential to replace nickel-based superalloys, which are currently used to make numerous turbine engine components.

**[0003]** Vacuum Arc Re-melting (VAR) is one technique commonly used to melt Ti alloys. VAR generally involves striking an arc between a titanium alloy electrode and pieces of the same alloy (electrode ends, for example) placed in a water-cooled copper crucible. A molten pool is established and the electrode progressively melts. When sufficient molten metal is available, the electrode can be withdrawn and the crucible tilted to pour the metal into a mold for casting components.

**[0004]** The VAR technique can have several drawbacks. Titanium electrodes used in the VAR process can be expensive because of the high cost of titanium billets/forgings, and the high cost of labor involved in creating an electrode from certified scrap or revert material. Also, the requirement for a pre-alloyed electrode can make it difficult and expensive to produce non-standard alloys. Furthermore, the need to use a water-cooled crucible can limit the degree of superheat achievable in the metal, which in turn can affect fluidity, leading to difficulty in filling thin-wall castings. Moreover, the highest temperature exists where the arc strikes the metal, and high temperature gradients exist in the molten metal. This can also affect the filling of molds and sets up poor temperature gradients in the solidifying casting.

**[0005]** In view of the previously described issues with VAR techniques, another method that can be employed when melting Ti alloys is Vacuum Induction Melting (VIM). VIM was developed for processing specialized and exotic alloys that contain reactive elements, such as titanium and aluminum, which cannot be melted and cast in air. As the use of such alloys continues to increase, VIM is consequently becoming more commonplace.

**[0006]** Vacuum induction melting generally involves

heating a metal in a crucible made from a non-conductive refractory alloy oxide until the charge of metal within the crucible is melted down to liquid form. In this technique, pieces of solid titanium alloy are placed in a cooled metal hearth, usually made of copper, and melted in an inert atmosphere using a very intense heat source, such as an arc or plasma. A molten pool will form initially on the interior and top surface of the charge of titanium while the titanium adjacent to the confining wall of the copper hearth remains solid. This "skull" of solid titanium that develops contains the liquid titanium metal free of contamination. See U.S. Patent No. 4,654,858, issued to Rowe for a general discussion of cold wall induction melting.

**[0007]** As referenced previously, copper crucibles are most often employed in cold wall induction melting of highly reactive alloys for a number of reasons. For example, melting and casting from ceramic crucibles can introduce significant thermal stress on the crucible, which can result in the crucible cracking. Such cracking can reduce crucible life and cause inclusions in the component being cast. Moreover, the highly reactive TiAl alloys can break down the ceramic crucible and contaminate the titanium alloy with both oxygen and the refractory alloy from the oxide. Similarly, if graphite crucibles are employed, the titanium aluminide can dissolve large quantities of carbon from the crucible into the titanium alloy, thereby resulting in contamination. Such contamination can result in a loss of mechanical properties of the titanium alloy.

**[0008]** Copper is less likely to exhibit the previously described problems associated with ceramic and graphite crucibles, which is why copper crucibles are typically employed when using cold wall induction melting to melt highly reactive metal alloys.

**[0009]** However, while cold crucible melting in copper crucibles can offer metallurgical advantages for the processing of the highly reactive alloys described previously, it can also have a number of technical and economic limitations including low superheat, yield losses due to skull formation and high power requirements. In particular, the cold wall induction crucible suffers heat loss when the power to the crucible is terminated and the metal is allowed to slump against the water-cooled copper sides of the mold.

**[0010]** One development that has been employed to address the previously described issues with vacuum induction melting is bottom pouring from a cold hearth melting system through a nozzle. See U.S. Patent Nos. 4,546,858 issued to Rowe and 5,164,097 issued to Wang et al. The nozzle material typically employed has been copper or brass, which are considered good thermal conducting materials. Graphite and thermally insulating materials have also been mentioned for use as nozzle material.

**[0011]** While the use of nozzles can provide many benefits over other common practices, the use of nozzles is not entirely without the potential for complications. For

example, cold hearth melting and bottom pouring of reactive metals like titanium can result in undesirable melt freeze-off in the nozzle. In addition, many crucible/nozzle systems can struggle to provide the requisite control of liquid flow rate, minimize erosion of the nozzle, and minimize melt contamination.

**[0012]** Another development that has been employed to address the previously described issues with vacuum induction melting is levitation melting, which generally involves using energy from induction coils to electromagnetically suspend the metal being melted. See U.S. Patent 5,275,229, issued to Fishman et al. for a general discussion of levitation melting. However, while the magnetic induction field can both heat the metal and hold the molten metal suspended in space within the crucible, once the power source for the system is turned off, the metal can slip back into the water-cooled crucible and chill again before it can be poured. This can result in incomplete filling of the mold.

**[0013]** Therefore, in spite of such advances, there remains a need for improved methods for melting highly reactive metal alloys, such as TiAl, that allow the alloy to remain molten during pouring, yet reduces the occurrence of the issues associated with conventional melting processes.

#### BRIEF DESCRIPTION OF THE INVENTION

**[0014]** Embodiments herein generally relate to methods for centrifugally casting a highly reactive titanium metal comprising providing a cold wall induction crucible having a plurality of induction coils and a removable bottom plate, using a power source to heat a titanium metal charge in the induction crucible to obtain a molten metal, preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine, positioning the centrifugal casting machine having the secondary crucible beneath the induction crucible, withdrawing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten metal to fall from the induction crucible into the secondary crucible, and accelerating the secondary crucible to centrifugally force the molten metal into a casting mold to produce a cast component.

**[0015]** Embodiments herein also generally relate to methods for centrifugally casting a highly reactive titanium metal comprising providing a cold wall induction crucible having a plurality of induction coils and a removable bottom plate, using a power source to heat a titanium metal charge in the induction crucible to obtain a molten metal, preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine, positioning a funnel beneath the induction crucible, positioning the centrifugal casting machine having the secondary crucible beneath the funnel, withdrawing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten metal to fall from the induction crucible through

the funnel and into the secondary crucible, and accelerating the secondary crucible to centrifugally force the molten metal into a casting mold to produce a cast component.

**[0016]** Embodiments also generally relate to methods for centrifugally casting a highly reactive titanium aluminide comprising providing a cold wall induction crucible having a plurality of induction coils and a slidably removable bottom plate, using a power source to heat a titanium aluminide charge in the induction crucible to obtain a molten titanium aluminide, preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine, positioning a niobium funnel beneath the induction crucible, positioning the centrifugal casting machine having the secondary crucible beneath the niobium funnel, slidably removing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten titanium aluminide to fall from the induction crucible through the niobium funnel and into the secondary crucible, keeping the secondary crucible stationary for from about 0.5 to about 2 seconds after the molten titanium aluminide falls into secondary crucible, and accelerating the secondary crucible to from about 100 rpm to about 600 rpm within from about 1 second to about 2 seconds thereafter to centrifugally force the molten titanium aluminide into a casting mold to produce a cast low pressure turbine blade.

**[0017]** These and other features, aspects and advantages will become evident to those skilled in the art from the following disclosure.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0018]**

FIG. 1 is a schematic cross-sectional view of one embodiment of a cold wall induction crucible having a metal charge placed therein in accordance with the description herein;

FIG. 2. is a schematic cross-sectional view of one embodiment of a cold wall induction crucible having the bottom plate removed and the molten metal suspended therein in accordance with the description herein;

FIG. 3. is a schematic cross-sectional view of one embodiment of a centrifugal casting system in accordance with the description herein; and

FIG. 4 is a schematic perspective view of one embodiment of a component, a low pressure turbine blade, which can be cast in accordance with the description herein.

#### DETAILED DESCRIPTION OF THE INVENTION

**[0019]** Embodiments described herein generally relate

to methods for centrifugally casting highly reactive metals, and in particular titanium alloys and titanium aluminide alloys, into net shape components, though the description that follows should not be limited to such.

**[0020]** In accordance with the description herein below, a cold wall induction crucible 10 having a body 12, can be provided, as shown in FIG. 1. Body 12 can be made from any metal having good thermal and electrical conductivity, such as, for example copper. Body 12 may be water-cooled to prevent the copper from melting during the heating of the crucible. More particularly, copper generally melts at about 1900°F (about 1038°C) and TiAl melts at about 2600°F (about 1427°C), and the copper in the crucible can form a low melting eutectic with the titanium. Water-cooling the crucible can prevent this from occurring. Water-cooling inlet 24 and outlet 26 may be used to circulate the cooling water through a plurality of channels 28 positioned about body 12. While body 12 may have any shape desired and acceptable for use in induction melting, in one embodiment, body 12 may be generally shaped as a hollow cylinder. Body 12 may have a plurality of induction coils 14 positioned thereabout, which can be heated using a power source 21. Coils 14 can serve as a heat source to melt a metal charge placed within the crucible and maintain its molten state, as described herein below.

**[0021]** Crucible 10 may also have a removable bottom plate 16 as shown in FIG. 1. Like crucible 10, bottom plate 16 may comprise any metal having good thermal and electrical conductivity, and in one embodiment, may comprise copper. Bottom plate 16 may also be water-cooled and have a plurality of induction coils 14 positioned thereunder, again, to help melt the metal charge placed with crucible 10 and maintain its molten state. Additionally, an electric insulator plate 19 may circumscribe bottom plate 16 to help maintain heat in the bottom of crucible 10. As described herein below, bottom plate 16 may be removed from body 12 in a variety of manners, including, but not limited to, sliding (as shown in FIGS. 2 and 3), rotating, dropping and the like.

**[0022]** In use, a metal charge 18 comprising a highly reactive alloy may be placed inside body 12 of crucible 10 as shown in FIG. 1. In one embodiment, metal charge 18 may comprise a titanium alloy, and more specifically a titanium aluminide alloy, and may take any acceptable form, which may include, but should not be limited to, lumps, ingots, granules, plates, powders, and mixtures thereof. Those skilled in the art will understand that the amount of metal charge 18 placed into crucible 10 can vary depending on intended use, however, in one embodiment, from about 1 pound (about 454 grams) to about 3.5 pounds (about 1588 grams), and in another embodiment from about 1.25 pounds (about 567 grams) to about 3.3 pounds (about 1497 grams) of metal charge 18 can be used to make net shaped low-pressure turbine blades as described herein below.

**[0023]** Once metal charge 18 is placed inside crucible 10, a cover 20, which in one embodiment, may be made

from the same material as crucible 10, may be positioned on top of body 12 and held in place with a cover ring 22, to ensure crucible 10 is sealed. Power source 21 may be turned on and metal charge 18 can melt when the appropriate temperature is attained, which in one embodiment may be from about 2700°F to about 2835°F (about 1480°C to about 1557 °C). Those skilled in the art will understand that the electromagnetic field generated by the induction coils causes the metal charge to heat itself internally due to resistance heating caused by current flow within the metal charge. As metal charge 18 begins to melt, the resulting molten metal 30 may become suspended within body 12 of crucible 10 such that molten metal 30 does not come into contact with the inside of body 12 as long as the power is being supplied to crucible 10. This suspension of molten metal 30 can prevent the formation of a skull.

**[0024]** Concurrent with melting the metal charge in induction crucible 10, a secondary crucible 32, or other like holding device, may be preheated using any acceptable means, such as, but not limited to, microwave or radiant energy. Secondary crucible may be made from graphite or ceramic, and may optionally have a metal liner, such as for example, niobium. Secondary crucible 32 can aid in the transfer of the molten metal to a casting mold without losing any of the superheat in the molten metal generated during induction melting in the induction crucible 10. More specifically, secondary crucible 32 can be preheated to at least about 1832°F (about 1000 °C), and in one embodiment from about 1832°F to about 2200°F (1000°C to about 1200°C), when secondary crucible 32 comprises niobium, and to at least about 1980°F (about 1082 °C), and in one embodiment from about 1980°F to about 2400°F (1082°C to about 1316°C), when secondary crucible comprises ceramic. Preheating can help prevent thermal shock and cracking of secondary crucible 32, which would allow for reuse thereof. Preheated secondary crucible 32 may then be placed in the rotating arm 34 of a centrifugal casting machine 36 and positioned below induction crucible 10, as shown generally in FIG. 3. Any conventional centrifugal casting machine is acceptable for use herein, such as for example, the Linn High-Therm Titancast 700 (Germany) or the SEIT Supercast (Italy).

**[0025]** Removable bottom plate 16 may then be withdrawn from body 12 of crucible 10, as previously described. In the embodiments shown in FIGS. 2 and 3, bottom plate 16 may be slidably removed from crucible 10 using any acceptable mechanism, such as, but not limited to, tracks or guides. Although bottom plate 16 is removed, the electromagnetic field generated by induction coils 14 can maintain molten metal 30 in a suspended state within body 12 of crucible 10 as shown in FIG. 2, until further processing.

**[0026]** When power source 21 is turned off, molten metal 30 is allowed to fall from induction crucible 10 through a niobium funnel 33 and into preheated secondary crucible 32, which can remain stationary within cast-

ing machine 36 just long enough for molten metal 30 to complete its transfer into secondary crucible 32, which in one embodiment may be from about 0.5 to about 2 seconds. Once the transfer of molten metal 30 is complete, secondary crucible 32 can be rapidly (about 1 to about 2 seconds) accelerated to full speed, which may be from about 100 rpm to about 600 rpm. Casting machine 36 can centrifugally force molten metal 30 out of secondary crucible 32 and into casting mold 38 through port 40, which may comprise at least one of a slit, hole, tube, or combination thereof. This quick transfer from secondary crucible 32 to casting mold 38 results in a contact time between the two of less than about 5 seconds. This brief contact time not only significantly reduces heat loss, but also helps ensure that there is no undesirable reaction between the molten metal and the graphite or ceramic used to construct secondary crucible 32.

**[0027]** Casting mold 38 may comprise any ceramic investment casting system that provides an inert face coat and thermal insulating backing materials. As an example, in one embodiment, casting mold 38 may comprise a face coat including an oxide. As used herein, "oxide" refers to a composition selected from the group consisting of scandium oxide, yttrium oxide, hafnium oxide, a lanthanide series oxide, and combinations thereof. Furthermore, the lanthanide series oxide (also known as "rare earth" compositions) may comprise an oxide selected from the group consisting of lanthanum oxide, cerium oxide, praseodymium oxide, neodymium oxide, promethium oxide, samarium oxide, europium oxide, gadolinium oxide, terbium oxide, dysprosium oxide, holmium oxide, erbium oxide, ytterbium oxide, lutetium oxide, and combinations thereof. Casting mold 38 may comprise a backing including a refractory material selected from the group consisting of aluminum oxide, zirconium silicate, silicon dioxide, and combinations thereof, in a colloidal silica suspension.

**[0028]** Once the molten metal has been substantially transferred into casting mold 38, centrifugal casting machine 36 can be turned off. The resulting component, which in one embodiment may be a low pressure turbine blade 42, as shown in FIG. 4, can be removed from casting mold 38 using conventional practices. Because of the use of centrifugal casting, blade 42 needs little post-cast processing. The centrifugal forces generated by casting machine 36 provides for the optimized filling of casting mold 38 by improving the filling of thin sections of the mold, thereby providing a net shape component.

**[0029]** Moreover, because cold wall crucibles are used to melt the metal charge, there is less thermal stress on the crucible, and therefore, less crucible cracking. This can allow for both reuse of the crucible and fewer inclusions in the cast component. Additionally, since contact between the molten metal and secondary crucible is limited, there is a reduced likelihood of contamination of the molten metal from breakdown of the crucible. Less contamination can result in improved mechanical properties

of the titanium alloy.

**[0030]** This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to make and use the invention. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

**[0031]** Aspects of the present invention are defined in the following numbered clauses:

1. A method for centrifugally casting a highly reactive titanium metal comprising:

providing a cold wall induction crucible having a plurality of induction coils

and a removable bottom plate;

using a power source to heat a titanium metal charge in the induction crucible to obtain a molten metal;

preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine;

positioning the centrifugal casting machine having the secondary crucible beneath the induction crucible;

withdrawing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten metal to fall from the induction crucible into the secondary crucible; and

accelerating the secondary crucible to centrifugally force the molten metal into a casting mold to produce a cast component.

2. The method of clause 1 wherein the titanium metal charge comprises a titanium aluminide alloy.

3. The method of clause 1 comprising withdrawing the bottom plate of the induction crucible using a method selected from the group consisting of sliding, rotating and dropping.

4. The method of clause 1 wherein the cast component comprises a low pressure turbine blade.

5. The method of clause 2 comprising using the induction coils of the induction crucible to heat the met-

al charge to a temperature of from about 1480°C to about 1557°C to obtain the molten metal.

6. The method of clause 1 wherein the molten metal becomes suspended within the induction crucible. 5

7. The method of clause 2 comprising preheating the secondary crucible to a temperature of at least about 1000°C when the secondary crucible comprises niobium and at least about 1082°C when the secondary crucible comprises ceramic. 10

8. The method of clause 1 comprising:

keeping the secondary crucible stationary for from about 0.5 to about 2 seconds after the molten metal falls into the secondary crucible; and 15

thereafter accelerating the secondary crucible to from about 100 rpm to about 600 rpm within from about 1 second to about 2 seconds to centrifugally force the molten metal into the casting mold. 20

9. The method of clause 1 wherein the casting mold comprises an oxide selected from the group consisting of scandium oxide, yttrium oxide, hafnium oxide, a lanthanide series oxide, and combinations thereof. 25

10. A method for centrifugally casting a highly reactive titanium metal comprising: 30

providing a cold wall induction crucible having a plurality of induction coils and a removable bottom plate; 35

using a power source to heat a titanium metal charge in the induction crucible to obtain a molten metal; 40

preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine; 45

positioning a funnel beneath the induction crucible; 50

positioning the centrifugal casting machine having the secondary crucible beneath the funnel; 55

withdrawing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten metal to fall from the induction crucible through the funnel and into the secondary crucible; and 55

accelerating the secondary crucible to centrifugally force the molten metal into a casting mold

to produce a cast component.

11. The method of clause 10 wherein the titanium metal charge comprises a titanium aluminide alloy.

12. The method of clause 10 comprising withdrawing the bottom plate of the induction crucible using a method selected from the group consisting of sliding, rotating and dropping.

13. The method of clause 10 wherein the cast component comprises a low pressure turbine blade.

14. The method of clause 11 comprising using the induction coils of the induction crucible to heat the metal charge to a temperature of from about 1480°C to about 1557°C to obtain the molten metal.

15. The method of clause 10 wherein the molten metal becomes suspended within the induction crucible.

16. The method of clause 11 comprising preheating the secondary crucible to a temperature of at least about 1000°C when the secondary crucible comprises niobium and at least about 1082°C when the secondary crucible comprises ceramic.

17. The method of clause 10 comprising:

keeping the secondary crucible stationary for from about 0.5 to about 2 seconds after the molten metal falls into secondary crucible; and

thereafter accelerating the secondary crucible to from about 100 rpm to about 600 rpm within from about 1 second to about 2 seconds to centrifugally force the molten metal into the casting mold.

18. A method for centrifugally casting a highly reactive titanium aluminide comprising:

providing a cold wall induction crucible having a plurality of induction coils and a slidably removable bottom plate;

using a power source to heat a titanium aluminide charge in the induction crucible to obtain a molten titanium aluminide;

preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine;

positioning a niobium funnel beneath the induction crucible;

positioning the centrifugal casting machine hav-

ing the secondary crucible beneath the niobium funnel;

slidably removing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten titanium aluminide to fall from the induction crucible through the niobium funnel and into the secondary crucible;

keeping the secondary crucible stationary for from about 0.5 to about 2 seconds after the molten titanium aluminide falls into secondary crucible; and

accelerating the secondary crucible to from about 100 rpm to about 600 rpm within from about 1 second to about 2 seconds thereafter to centrifugally force the molten titanium aluminide into a casting mold to produce a cast low pressure turbine blade.

19. The method of clause 18 comprising using the induction coils of the induction crucible to heat the metal charge to a temperature of from about 1480°C to about 1557°C to obtain the molten metal.

20. The method of clause 19 comprising preheating the secondary crucible to a temperature of at least about 1000°C when the secondary crucible comprises niobium and at least about 1082°C when the secondary crucible comprises ceramic.

## Claims

1. A method for centrifugally casting a highly reactive titanium metal comprising:

providing a cold wall induction crucible having a plurality of induction coils

and a removable bottom plate;

using a power source to heat a titanium metal charge in the induction crucible to obtain a molten metal;

preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine;

positioning the centrifugal casting machine having the secondary crucible beneath the induction crucible;

withdrawing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten metal to fall from the induction crucible into the secondary crucible; and

accelerating the secondary crucible to centrifugally force the molten metal into a casting mold

to produce a cast component.

2. The method of claim 1, wherein the titanium metal charge comprises a titanium aluminide alloy.

3. The method of claim 1 or claim 2, comprising withdrawing the bottom plate of the induction crucible using a method selected from the group consisting of sliding, rotating and dropping.

4. The method of any one of the preceding claims, wherein the cast component comprises a low pressure turbine blade.

5. The method of claim 2, comprising using the induction coils of the induction crucible to heat the metal charge to a temperature of from about 1480°C to about 1557°C to obtain the molten metal.

6. The method of any one of the preceding claims, wherein the molten metal becomes suspended within the induction crucible.

7. The method of claim 2, comprising preheating the secondary crucible to a temperature of at least about 1000°C when the secondary crucible comprises niobium and at least about 1082°C when the secondary crucible comprises ceramic.

8. The method of any one of the preceding claims, comprising:

keeping the secondary crucible stationary for from about 0.5 to about 2 seconds after the molten metal falls into the secondary crucible; and thereafter accelerating the secondary crucible to from about 100 rpm to about 600 rpm within from about 1 second to about 2 seconds to centrifugally force the molten metal into the casting mold.

9. The method of any one of the preceding claims, wherein the casting mold comprises an oxide selected from the group consisting of scandium oxide, yttrium oxide, hafnium oxide, a lanthanide series oxide, and combinations thereof.

10. The method of any one of the preceding claims, further comprising:

positioning a funnel beneath the induction crucible; and positioning the centrifugal casting machine having the secondary crucible beneath the funnel.

11. A method for centrifugally casting a highly reactive titanium aluminide comprising:

- providing a cold wall induction crucible having a plurality of induction coils and a slidably removable bottom plate;  
 using a power source to heat a titanium aluminide charge in the induction crucible to obtain a molten titanium aluminide; 5  
 preheating a secondary crucible and placing the preheated secondary crucible into a centrifugal casting machine;  
 positioning a niobium funnel beneath the induction crucible; 10  
 positioning the centrifugal casting machine having the secondary crucible beneath the niobium funnel;  
 slidably removing the bottom plate of the induction crucible and turning off the power source to the induction crucible to allow the molten titanium aluminide to fall from the induction crucible through the niobium funnel and into the secondary crucible; 15  
 keeping the secondary crucible stationary for from about 0.5 to about 2 seconds after the molten titanium aluminide falls into secondary crucible; and 20  
 accelerating the secondary crucible to from about 100 rpm to about 600 rpm within from about 1 second to about 2 seconds thereafter to centrifugally force the molten titanium aluminide into a casting mold to produce a cast low pressure turbine blade. 25 30
- 12.** The method of claim 11, comprising using the induction coils of the induction crucible to heat the metal charge to a temperature of from about 1480°C to about 1557°C to obtain the molten metal. 35
- 13.** The method of claim 12, comprising preheating the secondary crucible to a temperature of at least about 1000°C when the secondary crucible comprises niobium and at least about 1082°C when the secondary crucible comprises ceramic. 40

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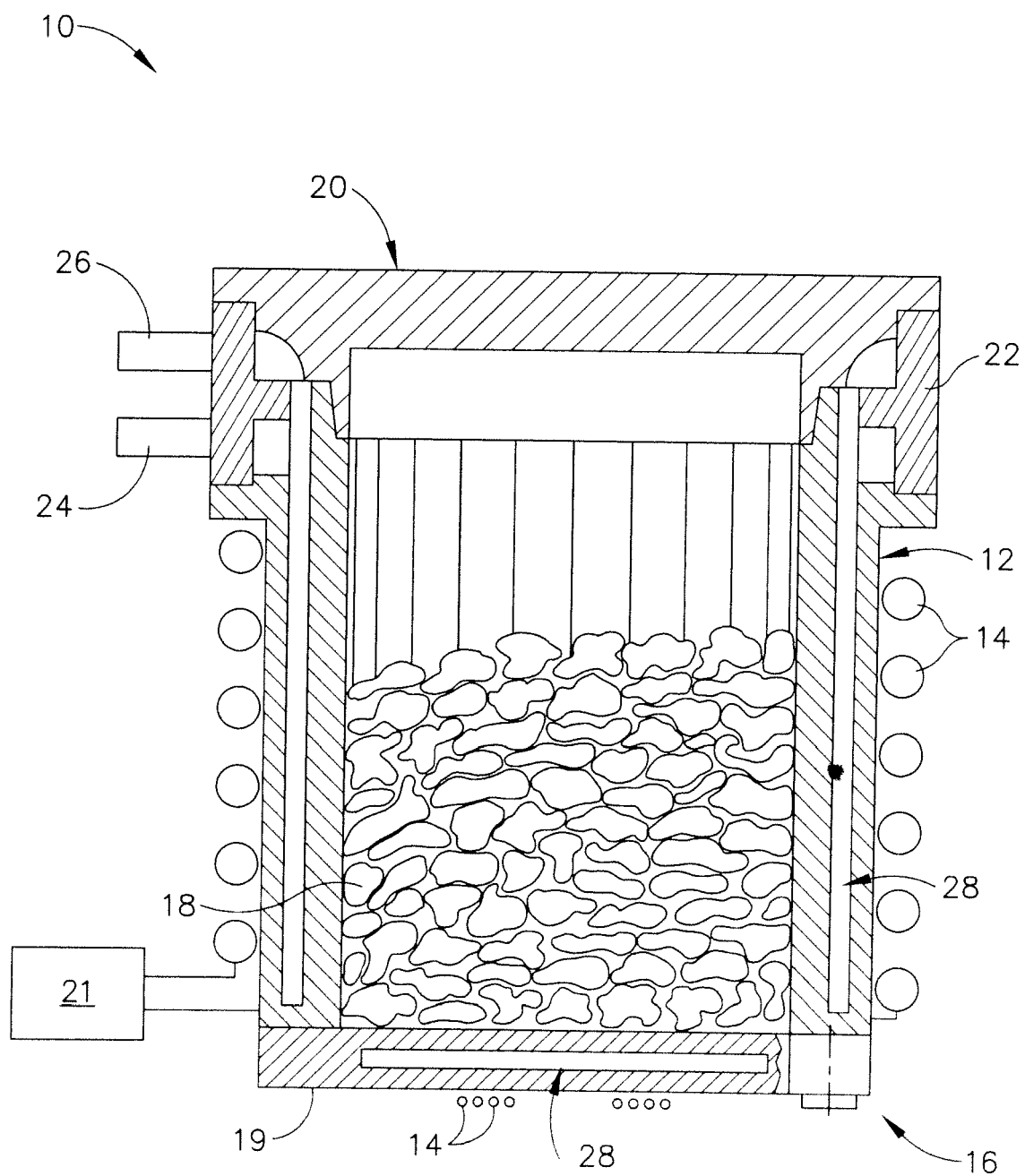


FIG. 1

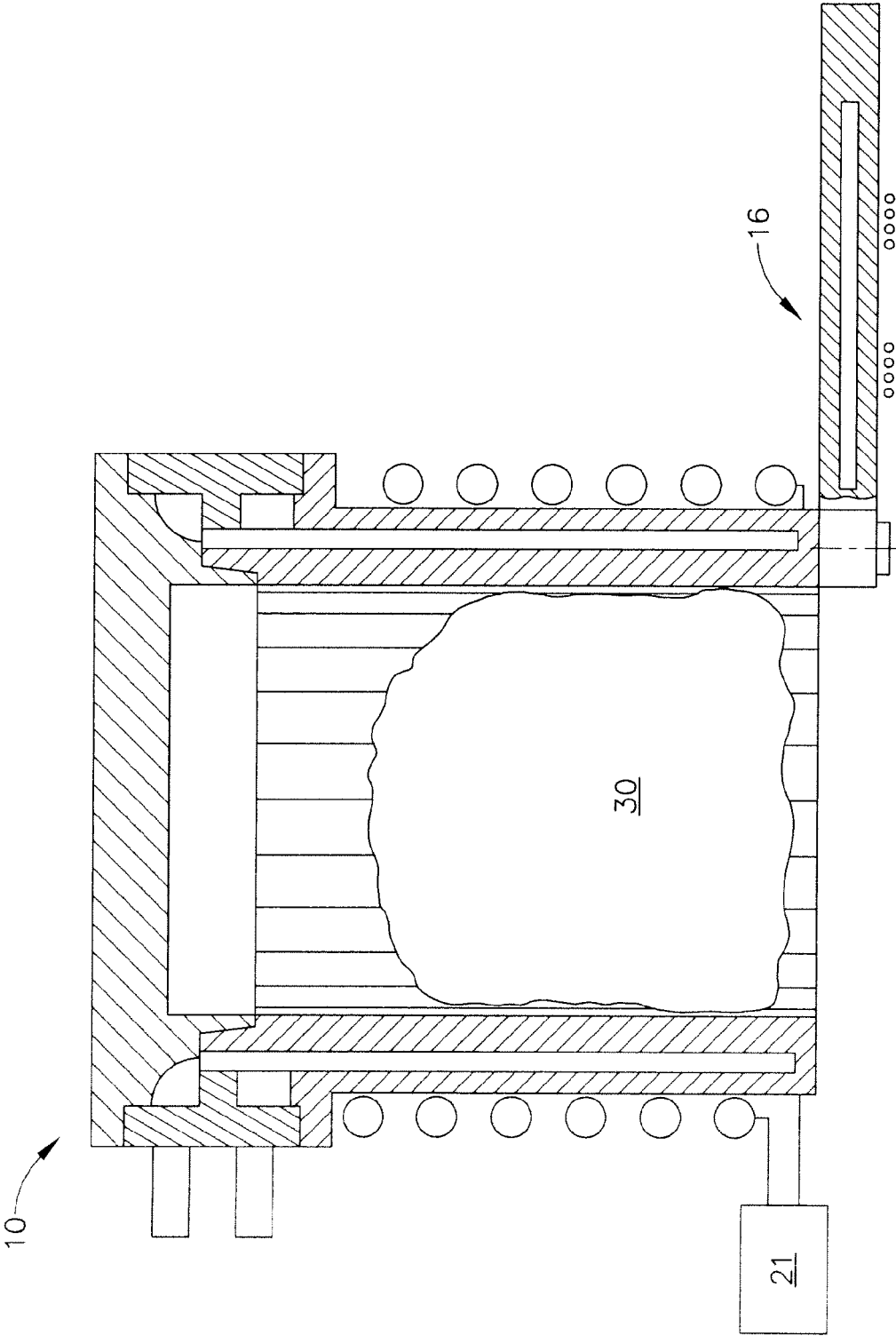


FIG. 2

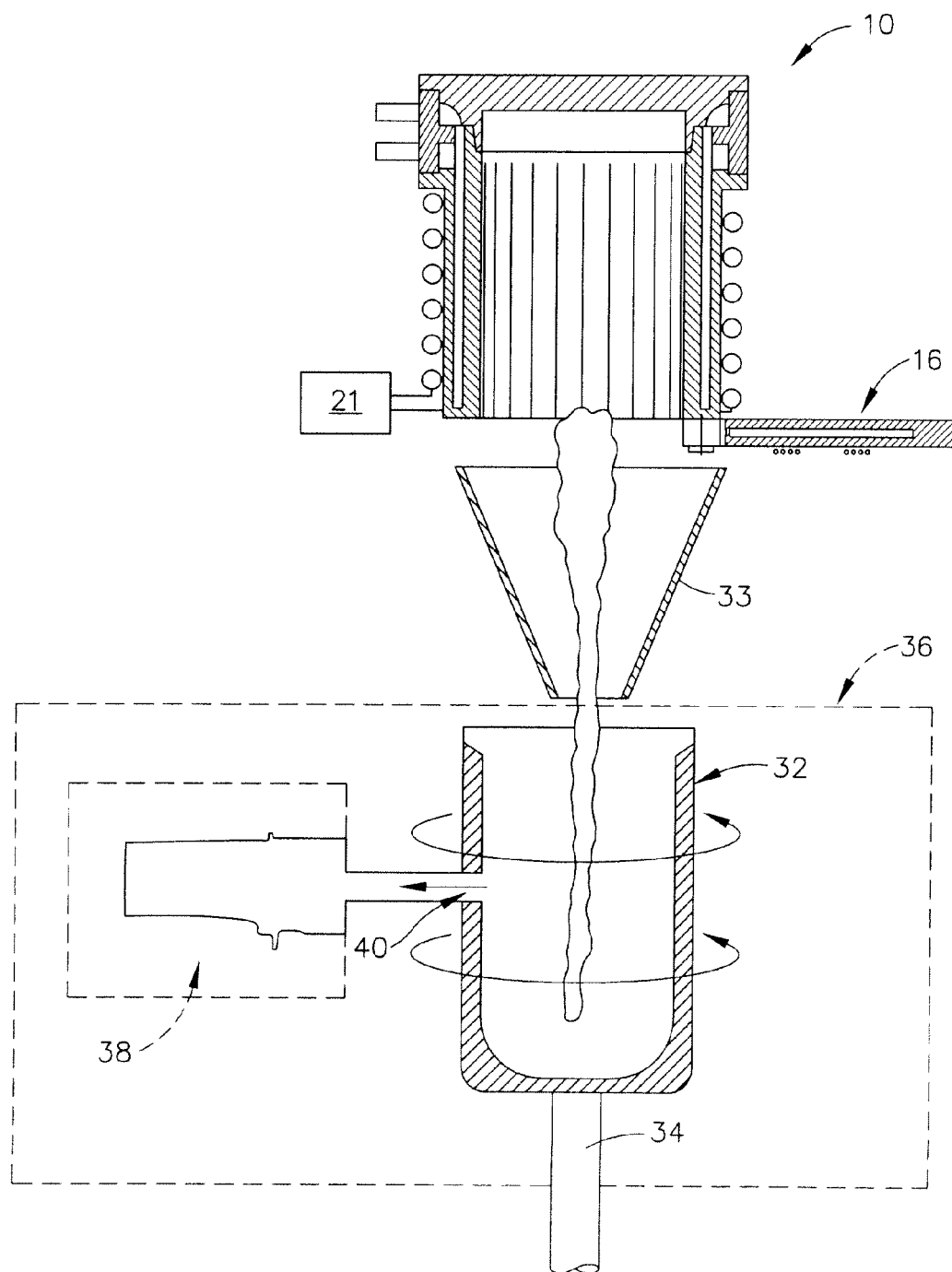


FIG. 3

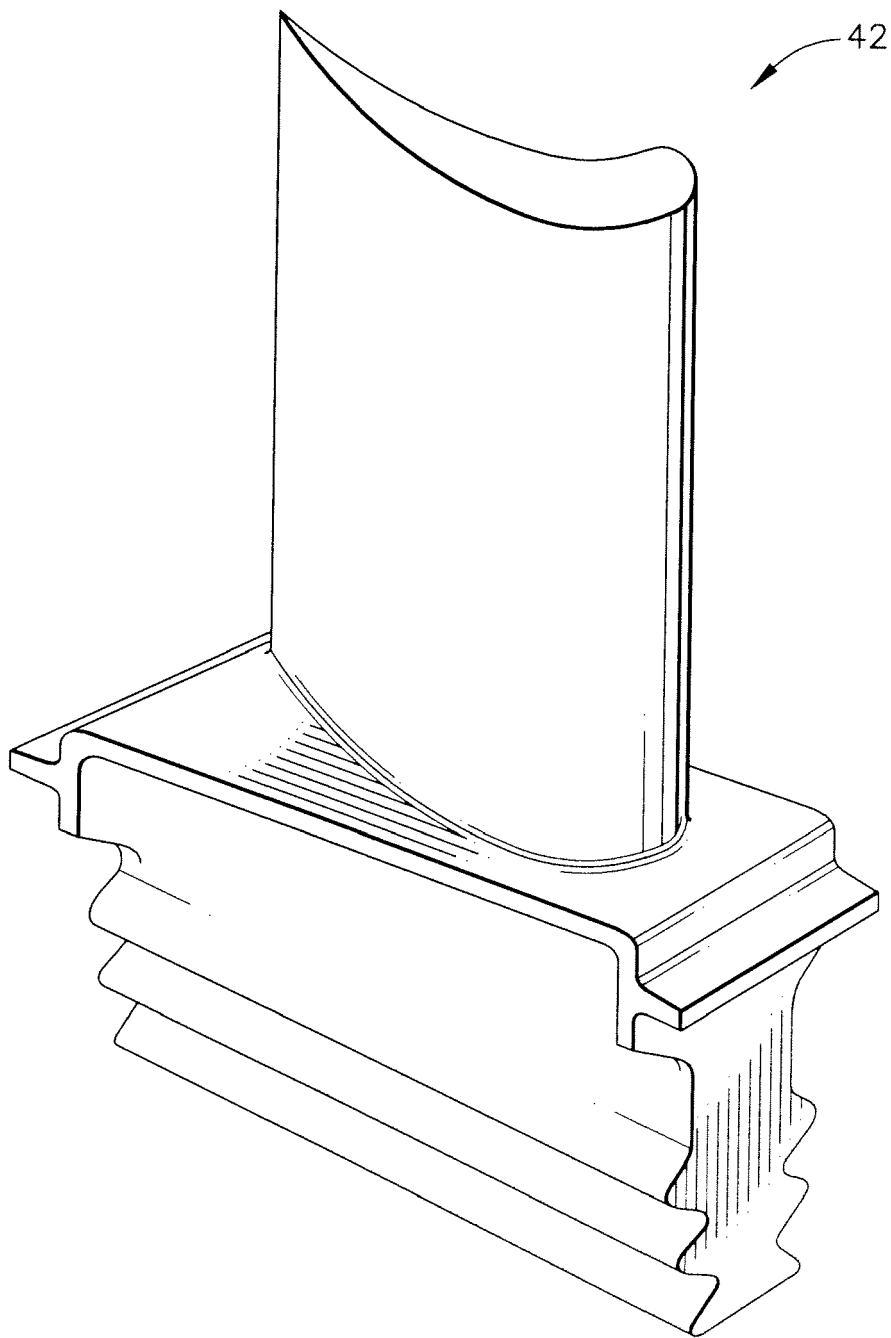


FIG. 4



## EUROPEAN SEARCH REPORT

Application Number  
EP 08 16 9707

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2001/045267 A1 (CHOUDHURY ALOK [DE] ET AL) 29 November 2001 (2001-11-29) * paragraph [0001] - paragraph [0066] * * figures 1,2 *	1-13	INV. B22D13/00
X	EP 0 686 443 A (ALD VACUUM TECHN GMBH [DE]) 13 December 1995 (1995-12-13) * column 4, line 42 - column 10, line 3 * * examples 1,2 * * figure 1 *	1-13	
X	US 2004/040690 A1 (RAY RANJAN [US] ET AL) 4 March 2004 (2004-03-04) * paragraph [0002] - paragraph [0154] * * figure 9 *	1-13	
X	CHOUDHURY A ET AL: "LOW COST PRODUCTION OF TIAL AUTOMOTIVE VALVES USING COLD WALL INDUCTION MELTING AND PERMANENT MOLD CENTRIFUGAL CASTING" CONFERENCE. ISATA. MATERIALS FOR ENERGY-EFFICIENT VEHICLES. PAINT AND POWDER COATING APPLICATIONS IN THE AUTOMOTIVE INDUSTRIES, XX, XX, 1 January 1997 (1997-01-01), pages 473-480, XP000882536 * the whole document *	1-13	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC) B22D
Place of search Munich		Date of completion of the search 6 February 2009	Examiner Zimmermann, Frank
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