Sept. 15, 1959 J. B. BRENNAN 2,903,759

CASTING OF REFRACTORY METALS

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FIG. 1

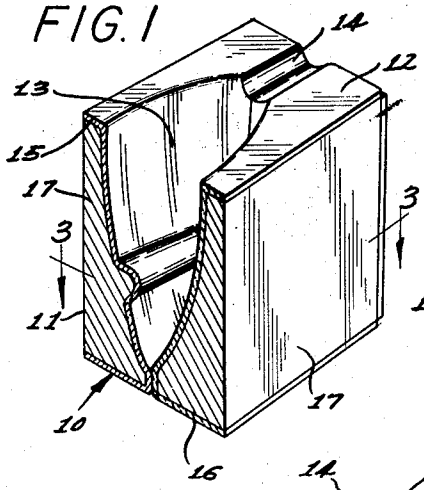


FIG. 2

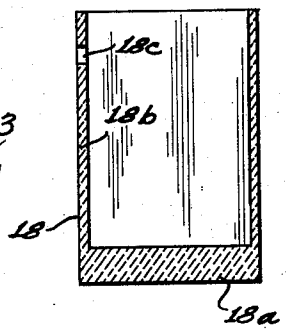


FIG. 3

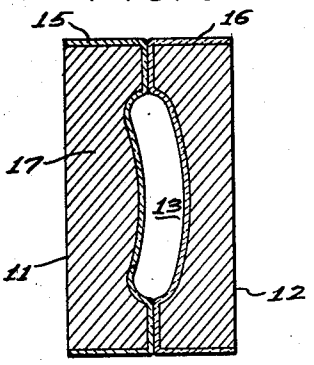


FIG. 4

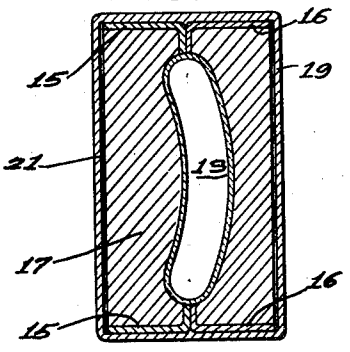


FIG. 5

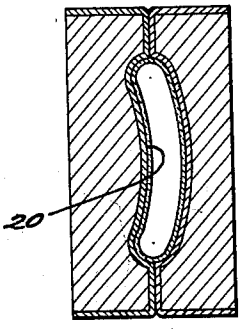
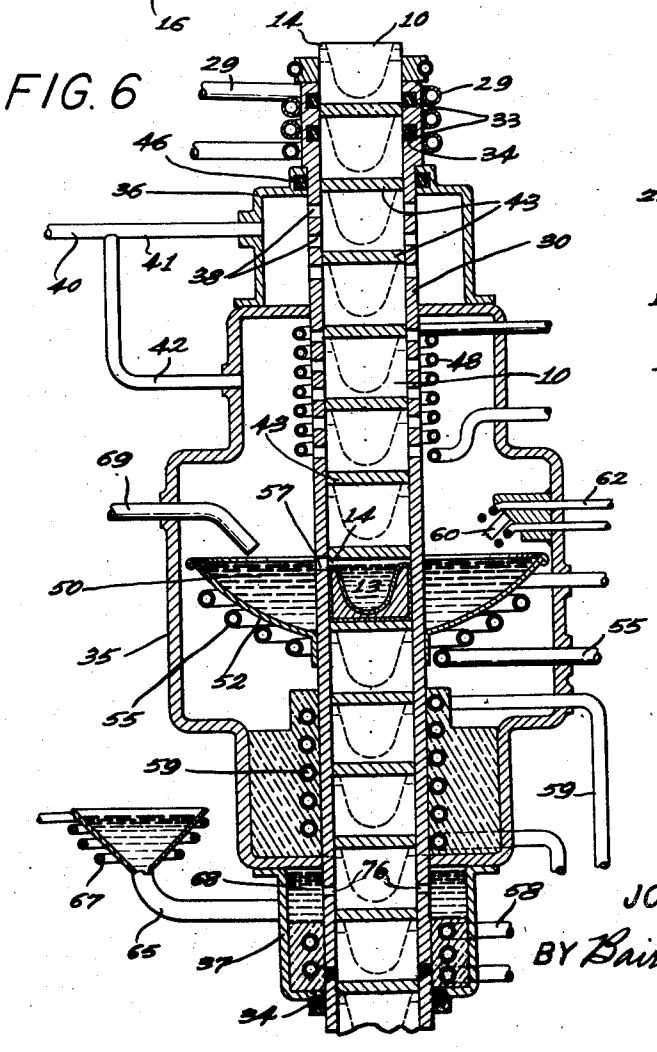


FIG. 6



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FIG. 7

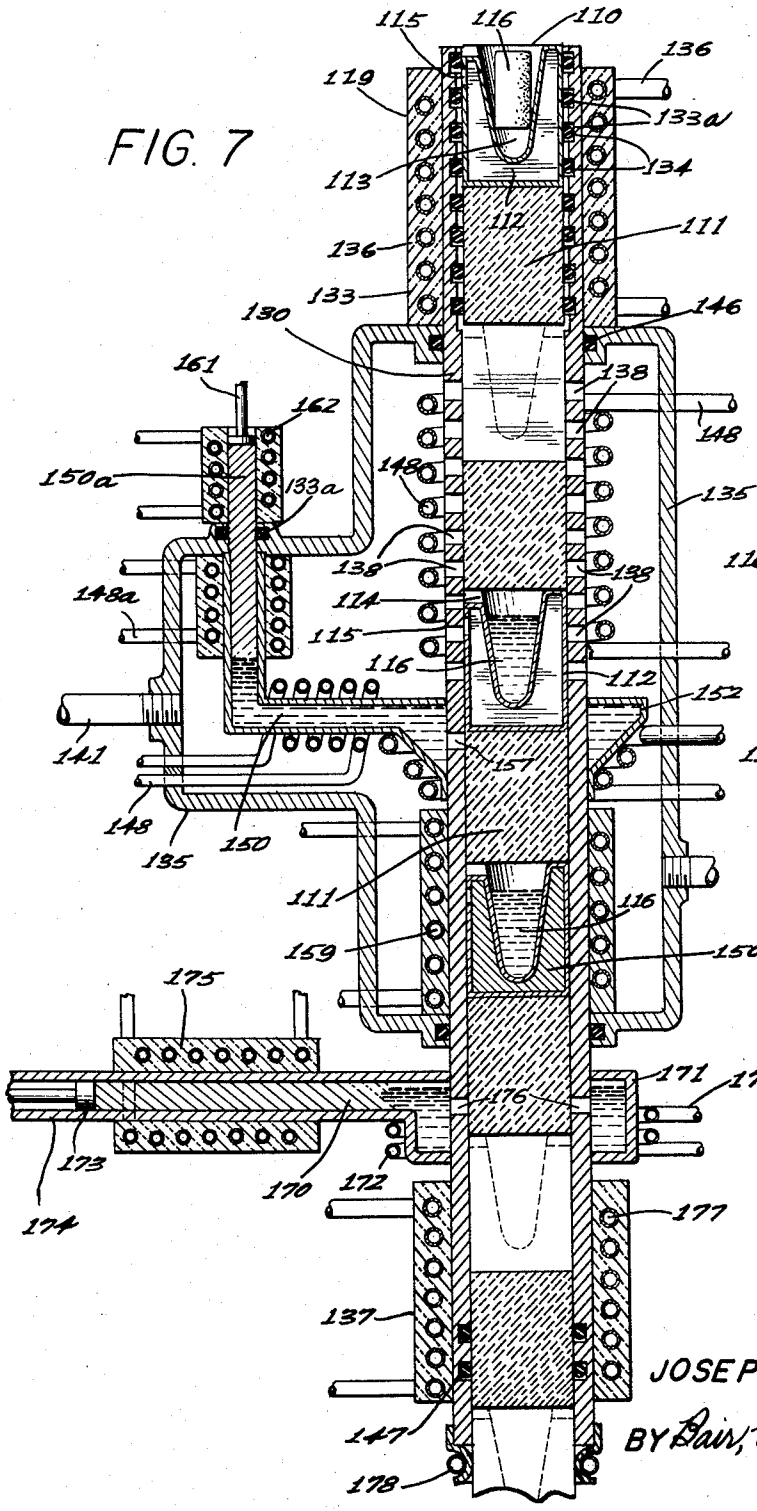
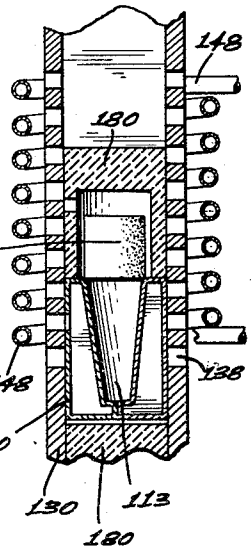


FIG. 8



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CASTING OF REFRACTORY METALS

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Application July 6, 1954, Serial No. 441,415

15 Claims. (Cl. 22—73)

The present invention relates generally to casting metals, and more specifically to a casting method and apparatus for shaping refractory metals including group IV of the periodic table of elements, such as titanium and its alloys.

In casting titanium, titanium alloys, and other highly refractory metals having a melting point in excess of 1500 or 1800° C. a primary problem is to prevent reaction between the molten casting metal and the surface of the mold. The reaction results in contamination of the metal, which adversely affects its properties, and in some cases the alloy resulting from the reaction is practically useless.

It is one object of this invention to provide a process and apparatus for casting titanium and other metals in which the temperature of the molten metal in contact with the mold cavity is rapidly reduced immediately upon pouring, to prevent, or markedly reduce, the reaction between the metal and the material comprising the surface of the mold cavity.

Another object is to provide a mold containing means for preheating the surface of the cavity to a temperature sufficiently high to de-gas the mold to prevent blowing of the casting, said means also being effective to reduce sharply the temperature of the high melting refractory metal poured into the cavity.

Another object of the invention is the provision of a method for casting in which a predetermined quantity of solid refractory metal to be shaped is placed in a mold cavity, heated above its melting point to fill the cavity, and then rapidly cooled under controlled conditions to solidify the metal.

Another object of the invention is to provide a mold having relatively thin refractory walls and contained within a thin-walled flask adapted to be filled with molten material at a temperature substantially below the temperature of the metal cast in the mold, to cool the casting.

A further object is to provide a vacuum casting apparatus comprising an elongated vacuum chamber through which the molds are adapted to pass, similar to pistons in a cylinder, means being provided for sealing the chamber between successive molds and between the side walls of the molds and the side walls of the chamber to prevent air from entering the vacuum chamber as the molds advance therethrough.

Another object is to seal the space between the molds and the vacuum chamber by coating the side walls of the mold with molten metal or glass.

Another object is to provide an apparatus and method for melting or sintering a metal in a mold and subsequently adding other molten material under differential pressure, said molten material serving to alloy or bond with or to cool said melted or sintered metal.

Another feature of this invention is the provision of a casting apparatus in which a succession of pools of molten metal are placed in partially or fully encompassing relation to a mold guide, said guide having openings therethrough which align with corresponding openings in a compartmented mold passing through said guide, whereby

metal from the pools may be fed into the desired compartment of the mold.

Other objects and advantages of the present invention will become apparent from the following description when read in conjunction with the drawings, in which:

Figure 1 is a vertical cross-sectional view through a mold made in accordance with the invention.

Figure 2 is a vertical sectional view through a flask adapted to contain the mold of Figure 1.

Figure 3 is a transverse cross-sectional view taken substantially along the line 3—3 of Figure 1.

Figure 4 is a cross-sectional view similar to Figure 2 showing a modified form of mold.

Figure 5 is a view similar to Figure 2 in which the mold cavity has a special coating.

Figure 6 is a vertical cross-sectional diagrammatic view illustrating a smelting and casting apparatus through which the casting molds shown in Figures 1 through 4 may be advanced for preheating, casting and cooling.

Figure 7 is a vertical cross-sectional diagrammatic view illustrating a smelting and casting apparatus wherein metal slugs or sinterings or powder may be placed above or in a cavitied mold member and for shaping by subsequent melting. Figure 7 also illustrates the use of alternate molds and sealing plugs for sealing the vacuum chamber of the mold guide or sleeve.

Figure 8 is a vertical cross-sectional diagrammatic view of the high frequency coil 148 shown in Figure 7 wherein the sealing plug has been modified to include a cavity for containing the mass of metal to be melted, evacuated and cast.

Referring now to Figures 1 to 3, the mold shown, identified generally by the numeral 10, comprises for example, two thin-wall complementary mating sections or halves 11 and 12 which divide a cavity 13 of any desired shape or size. A channel 14 may be provided in the top surface of the mold parallel with the parting line to facilitate the de-gassing of the melt and the mold cavity through the open upper end thereof. The complementary sections of the mold may be mechanically secured or may be cemented together as shown in the drawing by means of a refractory cement. Each mold section or half may be formed with a peripheral flange, section 11 having a peripheral flange designated as 15, and section 12 having a similar flange designated as 16. The space behind the mold cavity and between the flanges of each section is filled with a highly conductive material 17 such as aluminum, copper or silver, or other good thermal conductor. Since the melting and casting is preferably carried out within a vacuum chamber, it is desirable that the heat conductive material 17 be one which does not vaporize under the high vacuum as used. The mold sections 11 and 12 are formed from a refractory ceramic shell having a thin cross section, say, for example, less than one-eighth inch. Suitable materials for forming the shell are graphite, zirconia, alumina and silica. All of these materials will withstand for the time required, the very high temperature of molten titanium, which is in the vicinity of 1800° C., and will also withstand extreme temperature changes without cracking.

The mold of Figure 1 is preferably enclosed in a flask 18 shown in Figure 2, having a relatively thick bottom 18*a* and thin side walls 18*b*. Thus, when the thermally-conductive material 17 is raised to a temperature above its melting point it remains in contact with the thin walled mold halves 11 and 12, rather than flowing away. The flask preferably contains an opening 18*c* through which liquid coolant such as molten aluminum metal may be introduced to fill the space surrounding the mold cavity. As will appear hereinafter the molds are adapted to fit into a guide tube or sleeve so that a vacuum may be applied to the mold cavity during casting. The opening

18c in the flask may be located so as to align with a corresponding opening in the guide tube through which coolant may be introduced from a molten pool of thermally-conductive material. The flask has a smooth exterior surface so that it will slide within the guide tube, and may be made from graphite, alumina, zirconia and similar materials which are capable of resisting very high temperatures.

Figure 4 shows the mold of Figure 1 enclosed in a tight-fitting longitudinal sleeve **19**, which cooperates with flanges **15** and **16** to enclose the conductive coolant material **17**. The sleeve **19** serves the same purpose as the side walls of the flask **18** and prevents the molten coolant material from escaping from the space provided therefor behind the mold cavity. Sleeve **19** has a smooth external surface so that it will slide downward within the guide tube of the casting furnace. This sleeve may be made, for example, from stainless steel or refractory ceramic materials mentioned as suitable for the mold and flask.

In any case, there must also be a relatively thick, impervious, easy to seal plug of material such as graphite between or as a part of the molds so that these impervious plugs at the entrance and exit to the guide tube serve as sealing means to maintain the vacuum within the guide tube.

Other suitable means may be used for completely enclosing the conductive material **17**. For example, the mold halves **11**, **12** may have a refractory ceramic backing panel adhered to the upper edge of the flanges **15**, **16** with the silica cement. This panel may be of any thickness desired and may also act as an impervious barrier to vacuum leakage or impairment. It is preferable that a resilient sealing member surrounding the mold at all times be in engagement with the perimeter of this panel so as to prevent leakage.

It should be borne in mind that the conductive material **17** will expand considerably when heated and a space, as indicated at **21**, should be provided between the material and the confining sleeve **19** to accommodate the expansion.

To render the surface of the mold cavity less reactive to molten titanium and similar refractory metals, it is desirable to coat the cavity with an aluminum oxide film, or other protective coating. For example, aluminum metal may be applied to the surface of the cavity **13** in the form of foil, or it may be cast or sprayed on the surface of the cavity. The aluminum metal film may then, or prior thereto, be converted into aluminum oxide as, for example, in accordance with the process of my Patent No. 2,346,658. In Figure 5 the mold of Figure 3 is shown having such a coating, designated by the numeral **20**. Nickel and/or molybdenum may also be used as a coating for the mold cavity. Such coating is generally applied in a thickness not greater than 0.005 inch. The coating material may form an alloy on the surface of the casting or may comprise a separate film which later may be removed if it is not desired.

Another suitable material for coating the surface of the mold cavity to reduce and limit activity is carbon. Carbon may be applied in the form of a film of carbon black dusted onto the surface of the cavity, or by flame depositing or by colloidal coating.

According to one way of casting metals in accordance with my invention, the mold of Figure 1 is preheated to raise the temperature of the metal **17** to at least 300° C., and preferably from 750 to 1000° C. Heat from the mass of metal **17** is rapidly transferred to the ceramic lining of the cavity to drive off adsorbed gases or moisture. It will be noted that the temperature range recited is sufficiently high in the upper portion to cause some of the suitable conductive material to become molten. Aluminum, for instance, melts at 659° C. When these higher temperatures are employed it is necessary to enclose the mold in flask **18** or sleeve **19** as shown in Figure 4. The molten refractory metal to be cast is poured into the cavity of the preheated mold while a vacuum is being applied to the cavity to prevent inclusion of any air. It is very important that the casting step be carried out in the absence of air and, if desired, an inert atmosphere comprising a gas such as, for example, argon or other inert gas may be used. The temperature of the molten metal in contact with the surface of the cavity is immediately reduced as the heat is absorbed by the material **17**. Hence, there is little opportunity for chemical reaction to take place. The mold is then subjected to external cooling which causes solidification of the casting and then of the molten material **17**. Heat is continually conducted away from the mold through the mass conductive material **17** until the casting has been cooled to the point where it can be removed from the mold. The temperature at which the molten metal is poured, for example, may be upwards of 800° higher than the temperature of the mold surface, and consequently, the heat flow is from the molten metal to the mold, causing the surface of the casting to solidify almost immediately, and form at least a solid skin on the casting.

A suitable apparatus for carrying out the method of the invention is shown in Figure 6. This apparatus is particularly suitable for lower melting metals such as steel while the apparatus of Figure 7 is particularly suitable for refractory metals like titanium. Guide tube **30**, having a cross section the same as that of the mold, is adapted to receive successive molds to be charged with molten metal. The upper end of the tube is enclosed in cooling coils **29** through which cooling fluid is circulated. This prevents the diameter of the opening from expanding excessively and the sealing rings mentioned hereinbelow from overheating. A series of circumferential slots **33**, located within the cooled zone of the coils **29**, are fitted with resilient gaskets or packings **34** to form a seal with the external surface of the mold, thus preventing atmospheric air from entering the guide tube **30**. If desired, rings like piston rings may be used in place of gaskets **34**, provided they have a slight taper to give a lead to the mold being inserted. The central portion of the guide tube **30** is enclosed in a housing **35** wherein the preheating, casting and cooling steps are carried out. The upper portion of the tube **30** is enclosed in a separate housing **36**, secured to the top of housing **35**. The chambers defined by the housings **36** and **35** are connected to a vacuum line **40** through pipes **41** and **42**, respectively. The housing **36** is provided primarily to insure a high vacuum within the housing **35** and evacuate the mold completely before casting takes place. Air carried into tube **30** between the molds and within the mold cavities is practically all removed through the vacuum line **41**.

The guide tube **30** contains a series of apertures **38** through the wall thereof which permits gas escaping from the molds to flow into the chamber surrounding the tube and be removed through the vacuum lines. If desired, inert gas may be introduced into the housing **35** continuously and recirculated to insure an inert atmosphere during casting. O-ring **46** serves to seal tube **30** where it joins the housing **36**. The gaskets, or O-rings, or packings **34** and **46** may be made from a resilient material, preferably one which is heat resistant, such as silicon rubber. Heat resistant, impregnated and resilient asbestos packings which are commercially available are also satisfactory.

The preheating zone within housing **35** includes a high frequency coil **48** which surrounds the guide tube **30** and is adapted to operate at a frequency that will rapidly heat the conducting metal **17** within the molds. The central portion of the tube within the housing **35** serves as a casting zone in which a pool of molten metal **50**, to be shaped in the mold, is provided in an at least partially surrounding crucible **52** surrounding the tube **30**. The metal is introduced through tube **69**. The crucible **52**

is of the usual type which is made from ceramic material surrounded by heating means, for example, a high frequency coil **55**, so that the metal **50** is retained molten by the inductive effect of the high frequency coil. Water circulated around the high frequency coil **55** keeps the coil cool. An opening **57** in the tube **30** communicates with the channel **14** in the top surface of the evacuated mold so that the molten metal to be shaped may flow therethrough into the mold cavity **13**. It will be seen from the drawing that the molds fit snugly within the tube **30** so that the metal cannot flow out of the crucible **52** until such time as the channel **14** becomes aligned with the aperture **57**. The lower portion of the tube within the housing **35** comprises a cooling zone, said zone being equipped with coil **59** surrounding and contacting the tube **30**. Water or other suitable cooling fluid is circulated through the coil **59** to conduct away heat and reduce the temperature of the casting to the point where it can be removed from the mold. Chilling the molds immediately results in improved physical properties of the casting, particularly where the rate of heat transfer is controlled.

For purposes of keeping the high temperature metal **50** in molten condition, radiant heating elements **60**, as of graphite or silicon carbide, with a high frequency coil **62** surrounding them, are provided, for example, just above the surface of the metal **50** in the crucible. The end of the element **60** is parabolic and focuses the heat centrally on the pool of molten metal. Other suitable heating means may be employed, as for example, an electric arc or a parabolic silicon carbide resistor. A detailed description of the casting apparatus may be found in my copending application Serial No. 406,809, filed January 28, 1954.

In a casting apparatus of the type described, molds eight inches in length and having cavities of about three cubic inches in volume may be moved downwardly through the guide tube **30** at a uniform speed of sixteen inches per minute. If desired, the molds may be moved intermittently through a distance of two inches, for example, and maintained in each of the preheating, casting and cooling zones for about four to five seconds. As soon as the channel **14** of the mold becomes aligned with the aperture **57**, the molten metal **50** flows rapidly into the evacuated cavity **13**, to fill the cavity.

Where the mold is made from two halves, there is a possibility that air may seep through the joint where the halves are joined. Therefore, it is desirable to insert solid ceramic plugs **43** between successive molds to prevent such entry of air, unless, of course, the mold is enclosed in a flask, in which case the bottom of the flask serves as a plug. It is preferable that the length and number of these plugs be such that one plug is always in sealing contact with the O-rings **34** at the entrance and exit of the guide tube to prevent atmospheric leakage.

To further improve the seal against atmospheric leakage a pool of molten sealant material **68** may be provided within the annular enclosure **37** near the lower end of the guide tube **30**. The molten material may be glass, lead or another relatively low temperature melting lubricant, and will flow through the openings **76** into the space between the molds and the guide tube. Molten material **68** is supplied through tube **65**, surrounded by high frequency heating coils **67**. Cooling coils **58** maintain the lower end of tube **30** in cool condition and prevent the sealant material **68** from escaping by solidifying it.

As indicated, the external surface of the mold or flask is smooth so that a tight sliding contact is made with the inside surface of the guide tube **30**. The finish of such surface is preferably about 70 microns, or better.

In operation, the air within the cavity **13**, and air trapped between molds and in the pores of the mold is evacuated within the housing **36**. The molds are separated by plugs **43** which prevent air seepage between the mold halves. As the mold **10** passes into the space surrounded by the high frequency coil **48**, the conductive metal **17** is heated to its melting point which, in the case of aluminum, is 659° C. The heat is immediately transferred to the lining of the mold cavity and is effective to de-gas the mold, thus removing materials that would volatilize upon filling of the cavity with the high temperature metal and blow the casting. As the mold advances past the casting station, molten metal flows into the cavity through the aperture **57**. The weight of the metal causes or assists the molds to move downwardly through the guide tube. Therefore, the walls of the mold cavity are relatively cool, and as soon as the high temperature casting metal contacts the wall it is immediately cooled. It will be noted that before the casting operation is complete the lower end of the mold **10** is already entering the cooling zone surrounded by the coil **59**. Thus, cooling of the casting is effected from the bottom up to prevent trapping of any gases that might evolve upon contact with the molten metal. The last mold in the tube **30** effectively seals off the tube **30** by cooperation with the gaskets **34**. The penultimate mold in the tube makes sealing contact with the first gasket before the lowermost mold is removed, and is further sealed by molten material **68**. A clamping ring (not shown) surrounds the lowest mold to frictionally brake the advance of the stack of molds in the guide tube.

Obviously, other means may be employed in casting high temperature metals in molds of the kind disclosed, although the apparatus described has proved to operate very satisfactorily. If desired, means may be provided to permit draining of molten conductive metal **17** from the mold immediately after casting and the space vacated filled with a cooler fluid to effect complete solidification of the casting. Suitable apparatus for carrying out the casting process, including the introduction of a second coolant into the mold, is the rotary indexing mold transfer table disclosed in my copending application Serial No. 406,809, filed January 28, 1954.

It will be apparent to those skilled in the art that the mold **10** may be of one-piece construction, formed over a destructible pattern or model. Such a pattern may be made from a low melting alloy, a thermoplastic resin, or a combustible material. The pattern is melted and poured out after the mold has set, and in the case of the combustible pattern, the same is burned out leaving a mold cavity **13** of the desired shape and size.

Figures 7 and 8 illustrate additional and somewhat modified apparatus for smelting and casting which is particularly suitable for shaping metals of group IV of the periodic table.

In accordance with the method employed in this modification, a predetermined quantity of the metal to be shaped is placed in the mold cavity in solid form, such as a slug or powder briquette. The mold must have a sleeve or flask, enclosing the hollow space surrounding the thin-walled cavity. The mold is then heated to de-gas the cavity and melt the charge of metal therein. As it advances within the guide tube, molten coolant metal flows into the space surrounding the cavity when the opening provided for this purpose becomes aligned with an opening in the guide tube connecting to a source of molten metal. In this way the casting is cooled initially with final cooling taking place as the mold passes a cooling coil surrounding the lower portion of the guide tube.

Referring now to Figure 7, a hollow walled mold **110**, enclosed in a flask or sleeve, having a smooth surface exterior **119**, is fed down into an embracing tube **130** as of graphite. This mold assembly is referred to as mold **110** in this description of Figure 7. The mold **110** may be cast of material such as finely ground 96% silicon oxide, and has a cavity therein with treated surface, if desired, to prevent or reduce reaction with highly reactive refractory metal such as group IV metals, and is in construction similar to the molds described above.

Mold **110** has one or more openings **115** leading to the enclosed chamber **112** surrounding the cavity **113** into which the final product, such as a group IV metal, may be melted. When the mold **110** is introduced into the tube **130**, or prior to such introduction, a slug of metal **116**, which it is desired to shape, is placed within the cavity in the mold **110** and as the mold **110** is moved down through the tube **130** it is sealingly embraced by surrounding resilient rings **134** in the recesses **133** of the tube **130**. The metal may be in the form of powder or a sintered shape as well as a slug, and the weight thereof is predetermined to fill the mold cavity when melted. The tube **130** at the entrance section is water cooled by the cooling coil section **136** closely embracing the tube **130**.

Plugs **111**, which may be a part of the mold **110** or separate members shaped to fit the guide tube **130**, are inserted alternately with the molds **110** to prevent leakage between the molds as they are progressively fed down into the vacuum chamber **135**.

The chamber **135** is sealed with O-rings **146** about the tube **130** as described above and serves to evacuate tube **130** through openings **138** by means of the pipe **141** which is connected to a source of vacuum. A high frequency coil **148** is provided surrounding the porous section of the tube **130** so that as the molds **110** and the plugs **111** progress downward through the high frequency coil **148** they become highly heated, and the slug or quantity of powdered metal, or sintered metal **116** within the cavity **113** of the mold **110** immediately melts.

The mold cavity **113** is vented through opening **114** leading to the exterior of the guide tube **130** through openings **138** to assist in evacuation of the mold cavity as the mold is lowered through the high frequency coil **148**. The mold **110** has also a wall opening **115** which aligns peripherally with an opening **157** in tube **130** so that the coolant metal **150** will flow by gravity through the opening **157**, into the hollow space **112**, surrounding the mold cavity. The at least partially surrounding pool of molten metal **150** is fully or partially enclosed within a ceramic crucible **152**, and is retained molten by the high frequency coils **148** thereabout in the vacuum chamber **135**. The cooling metal may be aluminum or other good thermal conductor which does not vaporize readily under vacuum. The coolant metal **150** is introduced into the crucible **152** through a wall of the vacuum chamber **135**, preferably in the form of a solid ingot **150***a* pushed through a tube-like opening by means of a suitable pusher member **161**. Water-cooled coils **162** surround the tube for the purposes of maintaining the ingot **150***a* solid until it reaches the zone inside the vacuum chamber where it is heated to above its melting point by the high frequency coil **148***a*. The solid, water-cooled section of the ingot **150***a* may also be sealed by sealing gaskets or O-rings **133***a* so as to prevent leakage of vacuum thereabout. The crucible **152** containing the molten metal may be open, or it may be sealed on top as shown in the drawing. The crucible **152** may be located outside of the vacuum chamber if desired.

After coolant metal **150** has entered the hollow space **112** of the mold **110**, solidification of the molten metal **116** in the cavity **113**, and also of the coolant metal, is effected rapidly and progressively as the mold passes through the embracing cooling coil **159** surrounding the tube **130** below the crucible **152**.

A sealant **170**, such as lead or glass, may be introduced around the mold as it is moved downward through the tube **130** and below the cooling coil. The at least partially surrounding crucible **171** which contains the molten sealant metal may be heated by the high frequency coil **172**, and lead **170** may be fed in by a pusher **173** in the tube **174**. The tube **174** has a cooling and solification zone **175** through which water flows to retain the metal **170** in the solid state until it comes within the influence of the high frequency coil **172**, whereupon it is melted and is fed through the openings **176** in the tube **130** to seal and lubricate the plugs and the molds as they move downward. Other sealing and lubricating materials can be substituted in place of lead, such as thermoplastic resins which are normally solid and which would solidify if by chance they were sucked upward inside the tube **130** within the embracing cooling coil **159**. The sealing means may be fully or partially within the vacuum chamber **135**, rather than below it as shown in Figure 7.

An additional cooling coil **177** may be placed around the tube **130** in the cooling chamber **137**. O-rings **147** within recesses in the wall of the tube effect additional sealing and garter spring brake member **178** may be used to retard the molds and the impervious sections therebetween against the pull of gravity as they exit from the tube at the lower end thereof. When filled with metal, the molds are relatively heavy. Brake **178** may be of any suitable mechanical construction, generally a simple friction device will meet the purpose.

A number of molten material supply chambers or crucibles may be placed about the guide tube **130**, with complementary openings in the tube which align with the mold openings. Thus, more than one type of material may be introduced successively either into the interior of the cavity of the mold itself or in the hollow chamber about this cavity, or to act as a sealant and lubricant for the moving molds and impervious plugs.

During all times of operation a top as well as a bottom surrounding sealing member is in contact with an axially impervious mold section or plug between the molds. Thus, it is important to provide enough O-rings at the top and bottom ingress and egress portions of tube **130**, to prevent flow of atmospheric air around the molds as they enter and leave the tube. The O-rings and the entrance and exit vacuum chambers are fluid cooled, and in this way are protected from extremely high temperatures.

In practicing the invention it is important that the molten cooling fluid melt at a temperature substantially below the melting point of the metal being cast, and be a good heat conductor. Preferably, its mass should be two to three times that of the metal being cast. Under these conditions the molten cast metal is immediately cooled through the thin-walled mold cavity to reduce to a minimum any reaction that might take place between the cast metal and the mold cavity or its lining.

Referring to Figure 8, which is the upper portion of the apparatus of Figure 7 at the heating coil **148**, the normally solid plug **111** has been modified to include a cavity and is designated by the numeral **180**. A slug or briquette of metal **116** to be shaped, larger than the mouth of the mold cavity **113**, may be placed within the cavity of the plug to supply the cavity **113** of mold **110** with molten metal. As the slug passes within the electrical field of coil **148** it is melted in a very few seconds. For example, a slug weighing four ounces will melt in four to ten seconds, when the coil **148** has a power of 100 kilovolt amperes and a frequency of 9600 cycles. The molten metal falls into the cavity **113** without splattering into the vacuum chamber since the cavity in the plug and in the mold are sealed off, though gas pervious.

The coils **148** may be enclosed in an active nonconductive ceramic material which insulates the coil and prevents scintillation. Under such conditions higher frequencies may be employed.

It will be understood that the method of feeding solid metals to the crucibles surrounding the guide tube and the method of feeding the molten metal to the mold, as shown in the vacuum chamber of Figure 7, can also be used in the apparatus of Figure 6.

Other modifications of my invention will occur to those skilled in the art and it is my intention not to limit the invention other than is necessitated by the scope of the appended claims.

This application is a continuation-in-part of my applications Serial No. 225,949, filed May 12, 1951, now Patent No. 2,716,790, issued Sept. 6, 1955, and Serial No. 202,707, filed December 26, 1950, now abandoned, insofar as they contain common subject matter.

What I claim is:

1. The method of casting refractory metal which comprises placing a predetermined amount of said metal in a mold having a thin-walled cavity backed by a hollow enclosed space, heating said metal to melt it and fill the mold cavity, and introducing molten thermally-conductive material at a temperature substantially below the melting point of said refractory metal into said hollow space to cool said casting through said thin wall.

2. The method of casting refractory metal which comprises placing a predetermined amount of said metal in a mold having a thin-walled cavity backed by a hollow enclosed space, evacuating said cavity and maintaining said vacuum while heating said metal to melt it and fill the mold cavity, and introducing molten thermally-conductive material at a temperature substantially below the melting point of said refractory metal into said hollow space to cool said casting through said thin wall.

3. The method of casting refractory metal which comprises placing a predetermined amount of said metal in a mold having a thin-walled cavity backed by a hollow enclosed space, evacuating said cavity and maintaining said vacuum while passing said mold through a high frequency electrical field to melt the metal and fill the mold cavity, and introducing molten thermally-conductive material at a temperature substantially below the melting point of said refractory metal into said hollow space to cool said casting through said thin wall.

4. An apparatus for casting metals including in combination an elongated refractory guide tube, the interior of which is connected to a source of vacuum, a series of molds adapted to slide through said tube, said molds being spaced from each other by close fitting disc-like plugs which seal the tube against air seepage through the molds, heating means associated with said tube for melting metal charged into said molds, and cooling means spaced from said heating means for cooling said molten metal prior to discharge of the mold from said tube.

5. An apparatus for casting metals including in combination an elongated refractory guide tube, the interior of which is connected to a source of vacuum, a series of molds adapted to slide through said tube, said molds being spaced from each other by close fitting disc-like plugs which seal the tube against air seepage through the molds, heating means associated with said tube for melting metal charged into said molds, means for introducing molten materials between the walls of said mold and the walls of said tube to seal the space around the molds, and cooling means spaced from said heating means for cooling said molten metal prior to discharge of the mold from said sleeve.

6. An apparatus for casting metals including in combination an elongated refractory perforated guide tube having its central portion enclosed in a vacuum chamber, a series of molds adapted to slide through said tube, each having an enclosed hollow space surrounding the cavity thereof, heating means associated with said tube for melting a solid charge of metal within the cavity of the mold, a receptacle containing molten cooling material joining said tube, filling means for introducing said molten cooling material into said hollow space of each mold as it advances past said receptacle and cooling means for conducting heat from said molten charge through said cooling material.

7. An apparatus for casting metals including in combination an elongated refractory perforated guide tube having its central portion enclosed in a vacuum chamber, a series of molds adapted to slide through said tube, each having an enclosed hollow space surrounding the cavity thereof, sealing rings at either end of said tube for making close contact with the side walls of said molds to seal the tube against air seepage, heating means associated with said tube for melting a solid charge of metal within the cavity of the mold, a receptacle containing molten cooling material joining said tube, filling means for introducing said molten cooling material into said hollow space of each mold as it advances past said receptacle and cooling means for conducting heat from said molten charge through said cooling material.

8. In a casting apparatus, guide means for directing a mold past a plurality of stations, a mold disposed in said guide means having a relatively thin ceramic refractory shell backed by a conductive metal, preheating means associated with said guide means adapted to melt the conductive metal and thus preheat the mold shell, casting means adjacent said preheating means for pouring molten casting metal into said preheated mold and cooling means adjacent said casting means effective to solidify the conductive metal within the mold and thus cool the shell to solidify the casting.

9. A method for casting refractory metal which comprises providing a mold having a relatively thin refractory shell backed by a conductive metal, said conductive metal having a melting point substantially lower than the melting point of the refractory casting metal, melting said conductive metal to preheat said mold, pouring molten refractory metal into said mold, and resolidifying said conductive metal to cool the refractory metal cast within the mold.

10. The mold of claim 8 in which the refractory shell is made from a ceramic taken from the group consisting of alumina, silica and zirconia and the conductive metal is aluminum.

11. The method of claim 9 in which the resolidification of the conductive metal is effected from the bottom of the mold upwardly.

12. The method of continuously casting refractory metal which comprises providing a succession of molds having an unshaped mass of said refractory metal in the cavities thereof, advancing said molds through a high frequency electrical field to degas and melt said metal so that the molten metal will flow by gravity to assume the shape of the mold cavity, and continuing to advance said molds through an embracing cooling zone whereby the shaped metal is solidified.

13. The method of continuously casting refractory metal which comprises providing a succession of molds each having a cavity of relatively thin refractory material surrounded by an enclosed hollow space, placing a predetermined unshaped mass of said metal in each said cavity, advancing said molds through a guide tube in which the molds are subjected successively to a vacuum to evacuate the cavity, a high frequency field to degas and melt the metal in the cavity, and a two-stage cooling zone in which first said enclosed hollow space is filled with a molten coolant material followed by cooling of the entire mold, whereby the casting is solidified, and removing said molds one at a time from said guide tube.

14. In a method of casting a heat softenable material which comprises providing a guide tube maintained at subatmospheric pressure and a succession of molds, each slightly spaced from the interior of said tube and having a cavity for shaping said material, and advancing said molds through said tube past a filling station communicating with said tube for filling said cavities with said material, the step of sealing the interior of said evacuated guide tube from ingress of gas from the atmosphere which comprises casting a layer of fluid heat softenable material on the outside of the mold to seal the space between the mold and the guide tube.

15. In a method of casting molten refractory metal which comprises providing a guide tube maintained at subatmospheric pressure and a succession of molds, each slightly spaced from the interior of said tube and having a cavity for shaping said metal, and advancing said

molds through said tube past a filling station communicating with said tube for filling said cavities with said metal, the step of sealing the interior of said evacuated guide tube from ingress of gas from the atmosphere which comprises casting molten lead on the outside of the mold to seal the space between the mold and the guide tube.

References Cited in the file of this patent

UNITED STATES PATENTS

1,812,172	Rohn	June 30, 1931
1,984,385	Sherwood et al.	Dec. 18, 1934
1,999,114	Sherwood et al.	Apr. 23, 1935
2,326,164	Payne	Aug. 10, 1943
2,557,971	Jacklin	June 26, 1951
2,631,344	Kennedy	Mar. 17, 1953
2,660,770	Davis	Dec. 1, 1953
2,672,661	Lutz	Mar. 23, 1954
2,682,692	Kohl	July 6, 1954
2,709,842	Findlay	June 7, 1955
2,716,790	Brennan	Sept. 6, 1955
2,803,046	Brennan	Aug. 20, 1957