United States Patent Office 3,279,006 Patented Oct. 18, 1966

3,279,006

METHOD OF PREPARING COMPOSITE CASTINGS

Charles W. Schwartz, Whitehall, Mich., and Harold L. Wheaton, Rolling Meadows, Ill., assignors to Martin Metals Company, a corporation of Delaware

No Drawing. Filed Dec. 30, 1963, Ser. No. 334,971
12 Claims. (Cl. 22—204)

This application is a continuation-in-part of our copending application Serial No. 191,415, filed May 1, 1962.

The present invention relates to the casting of metals and alloys. More particularly, it relates to composite metallic objects and to a method for metallurgically bonding metallic materials of dissimilar compositions and/or properties.

Briefly, the invention comprises a method of producing composite objects wherein molten metallic material is poured into contact with and bonded to a solid metallic object positioned within a refractory mold being maintained under a protective atmosphere, such as a high vacuum, which mold, prior to the pouring of the metallic material, has been treated under vacuum at an elevated temperature in the range between about 1000° F. and the temperature of incipient melting of the solid metallic object or the slump temperature of the refractory mold, whichever is the limiting upper temperature, and at the time of pouring, the molten metal is at a temperature between about 200° F. and 2000° F. higher than the mold temperature.

Composite metallic objects prepared in accordance with the method of this invention contain a cast metallic portion, a metallic object of suitable configuration which was solid at the time of pouring the cast portion and a bonding layer formed between said object and said cast portion by the interalloying of the metallic object with the poured metal to produce a metallurgically bonded zone.

Metals and alloys are selected for use as structural materials generally on the basis of qualifications adapting them to several requirements, i.e., high strength per unit weight, high temperature strength, resistance to oxidation, etc. The structural materials may exhibit one or more of the characteristics but generally are deficient in some respect which drastically limits the conditions of safe operating use. The deficiencies of various metals and alloys may be illustrated by reference to metals characterized by a high melting point. The refractory metal tungsten, for example, has the highest melting point of any metal (6170° F.), but its use for components subject to high temperature conditions, is limited to atmospheres free of oxygen because at temperatures above 1800° F. in air, tungsten oxidizes catastrophically. Oxidation is also a serious problem with other members of the metals characterized by high melting points such as molybdenum, vanadium, columbium, etc.

Attempts have been made to overcome the deficiencies of structural members prepared from metals and alloys by, for example, changing the composition of the surface of a member, by providing a new surface layer through welding or brazing of a metal sheet to a base, forming a layer about the base, and the like. Another method for providing a new surface layer on a metallic base is to coat a base with a metal such as zinc by dipping, such dipped coating having the ability to readily adhere to the base, and pouring a metallic surface layer under conditions to bond the poured metal to the adhered metal. A change in the surface of the base may be accomplished, for example, by carburizing a surface layer, by depositing on and diffusing into the surface of a base metal a protective coating such as chromium, aluminum, and the like, as by the so-called vapor deposition technique. Base metals having surfaces altered by the means heretofore in use, have not been completely acceptable where structural parts were subject to high temperature environments. For example, a vapor deposited surface coating does not maintain a constant composition but is subject to alteration by diffusion of elements into the surface layer. A thin diffused surface layer tends to "disappear" through a continuance of the diffusion process at high temperature which creates a new exposed alloy as distinct from, for example, a metallic base covered by an "insulating" layer of a specific metal or alloy.

Now, it has been discovered that a composite object can be formed with poured metallic material joined at one or more surfaces to a metallic object or objects and in thickness varying from a thin surface layer of sufficient thickness to be an effective protective barrier around a metallic core to a structural member active as a link between solid metallic objects or an appendage to a solid metallic object, with a proper bonding or transition layer of intermediate compositional makeup.

By protective barrier is meant a continuous surface layer, uniformly bonded to a core and being of controllable thickness, which layers are commonly called claddings.

A composite metallic object may be produced by melting a metallic material having a specific property desired in the poured portion thereof under vacuum, heating a refractory mold having a cavity therein adapted to receive melted metallic material and having a solid metallic object or element positioned therein with at least a portion of the surface thereof exposed within the cavity, under vacuum and pouring the molten metallic material while maintaining an inert atmosphere. The temperature to which the mold is heated will vary with such factors as the nature of metals and/or alloys being bonded, and configuration of the solid object within the mold and the area of the bonding zone, the relative masses of the solid and poured portions of the composite object to be formed, and the like. When dealing with so-called refractory metal alloys which are sensitive to the presence of small quantities of gases, the mold is preferably heated to a temperature at or above the pouring temperature of the molten material but not in excess of the slump temperature of the mold or the temperature of incipient melting of the solid metallic object, whichever is the limiting upper temperature. The heating of the refractory mold under vacuum is carried out for a period of time sufficient to permit the desired degree of evacuation of volatiles, for example, for a period from 5 minutes to 180 minutes. Following the vacuum treatment, the mold is cooled, if necessary, to a temperature establishing a satisfactory solidification gradient while maintaining a non-oxidizing atmosphere or vacuum, and the molten material is poured into the mold and the casting is cooled in vacuum or non-oxidizing atomsphere until solidified.

In accordance with this invention, a suitable mold capable of withstanding the heat treatment without slumping is treated under the interrelated conditions of temperature and vacuum, to accomplish a predetermined degree of degasification. For example, the mold may be treated at a relatively low temperature for an extended period or at a higher temperature for a shorter period for removal of a portion of the volatiles. However, when such conditions are encountered as susceptibility of the solid object to oxidation or the sensitivity of a so-called refractory alloy to small amounts of gas

in a mold, it is preferable to utilize vacuum and temperature conditions which will render the mold substantially inert at the temperature and vacuum conditions which will affect it when the molten metal is poured into the mold cavity. It will be recognized that inertness of the mold is not necessary to obtain sound metallurgically bonded zones with some alloys as some are not as sensitive to the presence of volatiles as other alloys.

The mold may have a metallic object or objects positioned therein at the time of forming the mold or inserted therein at a time prior to pouring of the molten material.

When the conditions dictate that the mold should be rendered inert by the removal of gas to the extent that substantially no volatiles will be expelled from the mold when the metal is being poured into the cavity thereof, quick conditioning of the mold can be attained by heating under vacuum to a high temperature, preferably close to an upper limiting temperature, i.e., the temperature of incipient melting of the solid metallic object or the slump temperature of the mold, and be heated at that temperature for a time sufficient to permit effective degassing. In order to achieve effective degassing, the entire mold and the metallic object within the mold must be brought to the desired temperature. Inasmuch as heat transfer through the relatively dry mass of solid particles of the mold is a slow process, the time of heating varies with the thickness of the mold. If the melting point of the solid metallic object is higher than the softening temperature of the refractory mold, the temperature to which the refractory mold may be raised in a preconditioning operation may be varied with the melting point and more specifically the pouring temperature of the molten metal, which pouring temperature is usually between 50° F. and 600° F. above the melting point temperature for the material being rendered molten. A preferred procedure, particularly when preparing claddings, is to heat the mold to a temperature above the pouring temperature of the molten metal for effective degassing and then to cool the mold to between 200° F. and 1200° F. below the pouring temperature of the molten metal to provide a suitable solidification gradient as is explained herein later. In the pouring of metal castings designed to operate at high temperatures, for example, blades, vanes or discs of gas turbine engines, the alloys generally melt at a temperature in the range between about 2400° F. and 2700° F. and are poured at temperatures in the range between about 2450° F. and 3000° F., into a refractory mold whose temperature is in the range between about 1600° F. and 2400° F.

One of the primary requisites for the successful operation of this process is a clean surface on the metallic object. The metallic object must be free, for example, of an oxide layer at the time of contact with molten metal if a sound metallurgical bond is to be formed. Generally, the heating of the mold and the meallic object under vacuum prevents or minimizes formation of oxide on the object during the steps just prior to casting. If, during the processing, for example, during the wax burnout, a metallic object cannot be prevented from acquiring an oxide layer, the oxide formation should be removed by means such as thermal or chemical treatment prior to pouring the molten metallic material. Alternatively, sectional shell molds, which permit insertion of metallic objects after dewaxing, can be used. Such sectional molds permit introduction of a metallic object after the dewaxing and the burn-out under oxidizing conditions which could result in the formation of an oxide coating on the metallic object.

Also, in the preparation of composite metallic objects, it is desirable that the refractory mold be substantially free from contaminants. Vacuum treatment of the mold at relatively high temperatures will eliminate contaminants and in addition may serve the purpose of

removing a volatile oxide layer from a solid metallic object, such as molybdenum, tungsten, vanadium, etc.

If a refractory mold having a solid metallic object positioned therein, such as a metallic core, has been subjected to a preheat treatment at a high temperature, for examples, below the temperature of incipient melting of the solid metallic object, but above the pouring temperature of the molten material, the mold is cooled prior to pouring of molten metal or alloy to a temperature sufficiently lower than the pouring temperature of the molten metal to establish a temperature difference such that a satisfactory solidification gradient can be developed. A pretreated refractory mold is generally cooled to a temperature between 200° F. and 2000° F. below the pouring temperature of the molten metal to establish a proper solidification gradient. Such a solidification gradient is necessary in order to produce a sound cast portion of the composite object and to prevent excessive diffusion of an element or a multiplicity of elements beyond a bonding layer. Two of the primary factors in the choice of the temperature to which the mold and enclosed solid object will be cooled prior to pouring molten metal, assuming that the pouring temperature of the molten mass would be the same and the configuration of the poured portion of the composite object also would be similar, is the relative masses of the solid and poured portions of the composite object. If the mass of the solid object is large relative to the mass of the poured portion of the composite object, one way to control the extent of the bonding zone is to utilize a relatively hot mold so that the molten metal will not be chilled before it has ample opportunity to bond to the solid object. If the mass of the solid object is small relative to the mass of the poured portion of the composite object, one way to control the depth of the bonding zone developed, is to utilize a mold having a relatively low temperature within the bounds described, and thereby speed initiation of solidification and cooling of the entire mass of metal within the mold to temperatures below those conducive to diffusion of metals from the molten to the solid mass and vice versa.

It will be recognized by those skilled in the art that alterations can be made in, for example, temperature of the mold, temperature of the molten metal being poured, etc., to compensate for relative masses of material within the mold, geometry of the solid objects, surface area of contact between solid and molten metal, etc. These compensations can alter the differential in temperature to be utilized at the time of pouring so that a particular combination may require utilization of a differential in temperature between the mold and poured metal which are at variance with the differentials indicated in the above discussed specific instances. The objective of control of solidification is usually attained by cooling the mold to a temperature in the range between about 1000° F. and 2400° F., and preferably in the range between 1600° F. and 2400° F., if the pouring temperature of the metal is between about 2450° F. and 3000° F. and the solid metallic object is of a type permitting high temperature pretreatment of the mold. Castings poured when the mold is at an appropriate temperature to establish a solidification gradient exhibit a proper fill-out and adequate feeding so that the defects known as porosity, shrinkage, stress cracks due to differential expansion characteristics, etc., will be minimized or eliminated.

Molten metal is poured into a pretreated mold while maintaining a protective atmosphere. After solidification, cooling of the casting and mold can be completed under atmospheric conditions, following which the casting is processed in the conventional manner of knockout, cutoff and finish grinding. As used in the claims, the language "protective atmosphere" is intended to include holding under vacuum, in an atmosphere of inert gas or in an atmosphere of non-oxidizing gas.

In a preferred embodiment of this invention, a mold suitable for use in the casting process of this invention is made from a material which is substantially non-reactive at temperatures above the melting point of the metal to be cast. Highly refractory, relatively inert materials such as quartz, zircon, zirconia, alumina, and the like, have been found to meet these requirements.

A mold formed from suitable non-reactive materials and produced with suitable sprues, gates, and the like, is preferably subjected to treatment in a chamber maintained at a vacuum of less than 100 microns, usually of less than 10 microns and if a substantially inert mold is desired, in a chamber maintained at a vacuum in the range between about 0.01 and 5 microns.

In preparing a shell or a refractory mold of a type useful in a process of this invention, models of the components of the casting are prepared from expendable pattern materials such as wax and equivalents thereof. The metallic object or a wax facsimile thereof and the other components are joined together in the desired form and a refractory mold formed by the conventional dip and stucco procedure. Refractory materials utilized in the dip and stucco operations are those which are substantially nonreactive at temperatures above the pouring temperature of the molten metal to be cast.

The refractory mold is heated to melt out the wax and to produce the pouring cavity. If the metallic object is not in the shell, the dewaxing may be accomplished by firing the mold at a temperature between 1300° F. and 1850° F. to remove any residual wax or other unwanted material such as carbonaceous or organic substances. If the metallic object is integral with the mold, the dewaxing may be accomplished by relatively low temperature thermal means or by chemical means such as by use of solvents which do not produce an oxide layer on the metallic object. Suitable solvents for the purpose are trichloroethylene, carbon tetrachloride, and the like.

One form of apparatus for carrying out the casting of composite metallic objects consists of a vacuum chamber having a melting furnace therein, a pumping system communicating with the interior of the chamber adapted to evacuate gases from the chamber and a heater station adapted to receive a mold moved into the vacuum chamber through a mold charging lock provided with apparatus for positioning the refractory mold in the pouring station within the heater.

The process for the preparation of the composite metallic objects of this invention permits wide choice in the properties and characteristics of both the solid metallic object and the cast metal or alloy.

The solid metallic object may vary from a single metal such as molybdenum, tungsten, columbium, tantalum, chromium, vanadium, hafnium, zirconium, titanium, uranium, iron, cobalt, nickel and alloys thereof. Terms used throughout this specification, such as molybdenum, tungsten, etc., are intended to cover the individual metal and alloys thereof. Likewise, the poured metal may vary from a single metal such as aluminum, nickel, etc., to alloys of a complex nature such as cobalt-base and nickel-base alloys. Combinations of interest are metallic cores clad with alloys having oxidation resistance at high temperatures, as well as other embodiments, such as wear resistant clad layers over tough, ductile core material or clad ingots which can subsequently be rolled. In still another embodiment, a solid metallic object may, by appropriate arrangement, be positioned to come in contact with molten metal only along a single surface or plane so that the molten metal solidifies to form an appendage of the composite object extending from said surface.

As used in the claims, the langage "the temperature of incipient melting of the metallic object but below the slump temperature of the mold" is intended to mean that the refractory mold is heated to some elevated temperature, but in no case exceeding either the temperature of incipient melting of the metallic core or the slump temperature of the mold, whichever is the lower temperature.

In order to more fully illustrate the invention, the following examples are included. These examples are intended to be illustrative only and are not to be construed as limitations on the invention.

Example I

A tungsten core is built into a wax replica of the desired casting shape together with wax replicas of gates, runner bars, etc. The wax replica of the overall pattern is invested with a suitable zircon mold by the "dip and stucco" procedure. After room temperature drying, the coated pattern is fired and dewaxed by a 10 second flash heating to about 1800° F. followed by low temperature dewaxing at a temperature of about 200° F. The heating operation removes most of the wax; the remainder of the wax adhering to the interior surface of the mold is removed by washing with trichloroethylene solvent.

This dewaxed mold is introduced into the vacuum chamber through a mold lock into position within the mold heater which consists of a graphite induction susceptor and a surrounding induction coil. The mold is heated to approximately 2800° F. and held at approximately that temperature for 30 minutes while a vacuum of less than 10 microns, as measured by a Phillips gauge, is maintained. After holding the mold for the above-stated time, the mold is cooled to approximately 1900° F.

Metallic elements for the cladding layer are introduced into an induction melting furnace operating within the evacuable chamber in quantities to form an alloy having the following composition:

13% chromium, 4.5% molybdenum, 2.25% columbium, 6.0% aluminum, 0.6% titanium, 0.01% boron, 0.08% zirconium, 0.15% carbon, and the balance nickel.

The metallic elements are reduced to molten form by heating to approximately 2500° F.

After the mold has been cooled to about 1900° F., the molten alloy is poured into the mold. When the pouring operation is complete, the composite object is held in the vacuum chamber for about 30 minutes, following which the mold is removed from the chamber through the mold lock and cooled to room temperature. The composite object having a nickel-base alloy, as an approximately ⅛ inch thick surface layer, clad to a tungsten core, has a smooth surface substantially free of pits and porosity. A study of the internal structure showed a metallurgically bonded layer substantially free of defects.

Example II

A molybdenum core is built into a wax replica of the desired casting shape together with wax replicas of gates, runner bars, etc. The wax replica of the overall pattern is invested with a suitable zircon mold by the "dip and stucco" procedure. After room temperature drying, the coated pattern is fired and dewaxed by a 10 second flash heating to about 1800° F. followed by low temperature dewaxing at a temperature of about 200° F. The heating operation removes most of the wax, the remainder of the wax adhering to the interior surface of the mold is removed by washing with trichloroethylene solvent.

This dewaxed mold is introduced into the vacuum chamber through a mold lock into position within the mold heater which consists of a graphite induction susceptor and a surrounding induction coil. The mold is heated to approximately 2900° F. and held at approximately that temperature for 25 minutes while a vacuum of less than 10 microns, as measured by a Phillips gauge, is maintained. After holding the mold for the above-stated time, the mold is cooled to approximately 1800° F.

Metallic elements for the cladding layer are introduced

into an induction melting furnace operating within the evacuable chamber in quantities to form an alloy having the following composition:

22% chromium, 9% molybdenum, 0.6% tungsten, 18.5% iron, 2% cobalt, 0.10% carbon, and the balance nickel.

The metallic elements are reduced to molten form by heating to approximately 2500° F.

After the mold has been cooled to about 1800° F., the molten alloy is poured into the mold. When the pouring operation is complete, the composite object is held in the vacuum chamber for about 30 minutes, following which the mold is removed from the chamber through the mold lock and cooled to room temperature. The composite object having a nickel-base alloy, as an approximately 0.1 inch thick surface layer, clad to a molybdenum core, has a smooth surface substantially free of pits and porosity. A study of the internal structure showed a metallurgically bonded layer substantially free of defects.

Example III

A pre-formed core has the following composition:

21½% chromium, 10% tungsten, 9% tantalum, 0.2% zirconium, 0.85% carbon, 0.01% boron, 1% iron, and the balance cobalt.

The alloy core is inserted into a wax replica of the desired casting shape together with wax replicas of gates, runner bars, etc. The wax replica of the overall patterns is invested with a suitable zircon mold by the "dip and stucco" procedure. After room temperature drying, the coated pattern is fired and dewaxed by a 10 second flash heating to about 1800° F. followed by low temperature dewaxing at a temperature of about 200° F. The heating operation removes most of the wax, the remainder of the wax adhering to the interior surface of the mold is removed by washing with trichloroethylene solvent.

This dewaxed mold is introduced into the vacuum chamber through a mold lock into position within the mold heater which consists of a graphite induction susceptor and a surrounding induction coil. The mold is heated to approximately 2200° F. and held at approximately that temperature for 50 minutes while a vacuum of less than 10 microns, as measured by a Phillips gauge, is maintained. After holding the mold for the above-stated time, the mold is cooled to approximately 1750° F.

Metallic elements for the cladding layer are introduced into an induction melting furnace operating within the evacuable chamber in quantities to form an alloy having the following composition:

22% chromium, 9% molybdenum, 0.6% tungsten, 18.5% iron, 2% cobalt, 0.01% carbon, and the balance nickel.

The metallic elements are reduced to molten form by heating to approximately 2550° F.

After the mold has been cooled to about 1750° F., the molten alloy is poured into the mold. When the pouring operation is complete, the composite object is held in the vacuum chamber for about 45 minutes, following which the mold is removed from the chamber through the mold lock and cooled to room temperature. The composite object having a nickel-base alloy, as an approximately 0.05 inch thick surface layer, clad to the alloy core, has a smooth surface substantially free of pits and porosity. A study of the internal structure showed a metallurgically bonded layer substantially free of defects.

Example IV

A columbium core is built into a wax replica of the desired casting shape together with wax replicas of gates, runner bars, etc. The wax replica of the overall pattern is invested with a suitable zircon mold by the "dip and stucco" procedure. After room temperature drying, the coated pattern is fired and dewaxed by a 10 second flash heating to about 1800° F. followed by low temperature dewaxing at a temperature of about 200° F. The heating operation removes most of the wax, the remainder of the wax adhering to the interior surface of the mold is removed by washing with trichloroethylene solvent.

This dewaxed mold is introduced into the vacuum chamber through a mold lock into position within the mold heater which consists of a graphite induction susceptor and a surrounding induction coil. The mold is heated to approximately 2750° F. and held at approximately that temperature for 30 minutes while a vacuum of less than 2 microns, as measured by a Phillips gauge, is maintained. After holding the mold for the above-stated time, the mold is cooled to approximately 1850° F.

Metallic elements for the cladding layer are introduced into an induction melting furnace operating within the evacuable chamber in quantities to form an alloy having the following composition:

20% chromium, 0.12% carbon, 0.4% titanium, and the balance nickel.

The metallic elements are reduced to molten form by heating to approximately 2450° F.

After the mold has been cooled to about 1850° F., the molten alloy is poured into the mold. When the pouring operation is complete, the composite object is held in the vacuum chamber for about 30 minutes, following which the mold is removed from the chamber through the mold lock and cooled to room temperature. The composite object having a nickel-base alloy, as an approximately 0.08 inch thick surface layer, clad to a columbium core, has a smooth surface substantially free of pits and porosity. A study of the internal structure showed a metallurgically bonded layer substantially free of defects.

Example V

A wax replica of a turbine blade is joined with a riser and pouring basin assembly adapted to provide a split mold separating at the parting line of the cavity, and the wax replica of the overall pattern is invested with a suitable zircon mold by the "dip and stucco" procedure using zircon and alumina. After room temperature drying, the coated pattern is fired and dewaxed by heating in an oven to about 1800° F. for about 30 minutes.

After cooling the shell to room temperature, an air foil section of a turbine blade is inserted into the split mold which leaves a cavity for the pouring of the root (bottom) section and the shell sealed with refractory slip to prevent leaking. This air foil section has the following composition:

0.15% carbon, 9% chromium, 10% cobalt, 12.5% tungsten, 1% columbium, 2% titanium, 5% aluminum, 0.05% zirconium, 0.02% boron, and the balance nickel.

This sealed shell is introduced into the vacuum chamber through a mold lock into position within the mold heater which consists of a graphite induction susceptor and a surrounding induction coil. The mold is heated to approximately 2000° F. and held at this temperature for 30 minutes while a vacuum of less than 10 microns is maintained.

Metallic elements for the appendage are introduced into an induction melting furnace operating within the evacuable chamber in quantities to form an alloy having the following composition:

0.15% carbon, 11% chromium, 20% cobalt, 5% molybdenum, 1.5% titanium, 5% aluminum, 0.05% zirconium, 0.015% boron, and the balance nickel.

The metallic elements are reduced to molten form by heating to approximately 2700° F.

The molten alloy at approximately 2700° F. is poured into the mold held at 2000° F. When the pouring operation is complete, the composite turbine blade is held in the vacuum chamber for about 30 minutes, following which the mold is removed from the chamber and cooled

to room temperature. The composite turbine blades show a metallurgically bonded zone.

Example VI

A replica of a turbine blade is joined with a riser and pouring basin assembly adapted to provide a split mold separating at the parting line of the cavity and the wax replica of the overall pattern is invested with a suitable zircon mold by the "dip and stucco" procedure using zircon and alumina. After room temperature drying, the coated pattern is fired and dewaxed by heating in an oven to about 1800° F. for about 30 minutes.

After cooling the shell to room temperature, an air foil section of a turbine blade and a forged root section of a turbine blade are inserted into the split mold so as to leave a short transition zone into which molten alloy is to be poured and the shell sealed with refractory slip to prevent leaking.

The air foil section has the following composition:

0.15% carbon, 9% chromium, 10% cobalt, 12.5% tungsten, 1% columbium, 2% titanium, 5% aluminum, 0.05% zirconium, 0.02% boron, and the balance nickel.

The forged root section has the following composition:

0.06% carbon, 15% chromium, 19% cobalt, 5.15% molybdenum, 3.5% titanium, 4.4% aluminum, 0.05% zirconium, 0.03% boron, 0.4% iron, and the balance nickel.

This sealed shell is introduced into the vacuum chamber through a mold lock into position within the mold heater which consists of a graphite induction susceptor and a surrounding induction coil. The mold is heated to approximately 2000° F. and held at this temperature for 30 minutes while a vacuum of less than 10 microns is maintained.

Metallic elements for the transition zone are introduced into an induction melting furnace operating within the evacuable chamber in quantities to form an alloy having the following composition:

0.15% carbon, 9% chromium, 10% cobalt, 12.5% tungsten, 1% columbium, 2% titanium, 5% aluminum, 0.05% zirconium, 0.02% boron, and the balance nickel.

The metallic elements are reduced to molten form by heating to approximately 2700° F.

The molten alloy is poured into the mold held at 2000° F. When the pouring operation is complete, the composite turbine blade is held in the vacuum chamber for about 30 minutes, following which the mold is removed from the chamber and cooled to room temperature. This composite turbine blade combines an air foil section possessing high temperature strength with a prefabricated root section of high strength and greater ductility at lower temperatures encountered in this section of turbine blades during engine operation, a combination of properties unattainable with any single alloy, and a transition zone of strength and ductility eliminating failures in this area.

In general, it will be understood that the details herein described are intended to be merely illustrative in character, and that the process may be modified readily by those skilled in the art without departure from the spirit and scope of the invention as expressed in the appended claims.

We claim:

1. A method of forming composite metallic objects comprising heating a refractory mold having a cavity therein and having a solid metallic element positioned therein which fills only a portion of said cavity, to a temperature in the range between about 1000° F. and the temperature of incipient melting of the metallic element but below the slump temperature of the mold while the mold is subjected to a vacuum of less than 100 microns, establishing a temperature level for the treated mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, pouring the molten metal into the treated mold to contact and to bond to said metallic element while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

2. A method of forming composite metallic objects comprising heating a refractory mold having a cavity therein and having a solid metallic element positioned therein which fills only a portion of said cavity, to a temperature in the range between about 1000° F. and the temperature of incipient melting of the metallic element but below the slump temperature of the mold while the mold is subjected to a vacuum in the range between about 0.01 and 10 microns for a period in the range between about 5 minutes and about 180 minutes, cooling the treated mold while the vacuum is maintained thereon to a temperature at which there is a temperature differential in the range between about 200° F. and 2000° F. between the cooled treated mold and the metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, pouring metal melted under vacuum into the treated mold to contact and to bond to said metallic element while the melt and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

3. A method of forming composite metallic objects comprising heating a refractory mold having a cavity therein and having a solid metallic element positioned therein which fills only a portion of said cavity, to a temperature in the range between about 1000° F. and the temperature of incipient melting of the metallic element but below the slump temperature of the mold while the mold is subjected to a vacuum of less than 100 microns, establishing a temperature level for the treating mold, heating molten metal under vacuum to a pouring temperature such that there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, pouring the molten metal into the treated mold to contact and to bond to said metallic element while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

4. A method of forming composite metallic objects comprising heating a refractory mold having a cavity therein and having a solid metallic element melting at a temperature above about 2400° F. positioned therein which fills only a portion of said cavity, to a temperature in the range between 1000° F. and the temperature of incipient melting of the metallic element but below the slump temperature of the mold while the mold is subjected to a vacuum in the range between about .01 and 100 microns for a period in the range between about 5 minutes and about 180 minutes, cooling the treated mold while vacuum is maintained thereon to a temperature at which there is a temperature differential in the range between 200° F. and 2000° F. between the temperature of the treated mold and the metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, pouring metal melted under vacuum at a temperature in the range between 2450° F. and 3000° F. into the cooled mold while the melt and mold are maintained under vacuum to contact and to bond to said metallic element and maintaining the vacuum on said mold until the cast metal is solidified.

5. A method of forming composite metallic objects comprising heating a refractory mold having a metallic core melting at a temperature above 3000° F positioned therein under vacuum to a temperature in the range be-

tween about 1000° F. and the temperature of incipient melting of the metallic core but below the slump temperature of the mold while the mold is subjected to a vacuum of less than 100 microns, establishing a temperature level for the treated mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, heating metal under vacuum to a molten state, pouring the molten metal into the treated mold to contact and to bond to said metallic element while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

6. The method of forming a composite metallic turbine blade comprising producing a refractory mold having a cavity therein in the configuration of a turbine blade, positioning a solid air foil section in the corresponding portion of the mold cavity, heating the mold and air foil section under vacuum to a temperature in the range between about 1000° F. and the temperature of incipient melting of the metallic element but below the slump temperature of the mold while the mold is subjected to a vacuum of less than 100 microns, establishing a temperature level for the treated mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, heating molten metal under vacuum, pouring the molten metal into the treated mold to contact and to bond to said metallic element while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

7. The method of forming a composite metallic turbine blade comprising producing a refractory mold having a cavity therein in the configuration of a turbine blade, positioning a solid air foil section in the corresponding portion of the mold cavity, heating the mold and air foil section under vacuum to a temperature in the range between about 1600° F. and 2400° F. while the mold is subjected to a vacuum of less than 100 microns, establishing a temperature level for the treating mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperatures of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, heating molten metal under vacuum, pouring the molten metal into the treated mold to contact and to bond to said air foil section while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

8. The method of forming a composite metallic object comprising producing a refractory mold having a cavity therein of desired form, positioning a solid metallic element therein to fill one portion of said cavity, heating the mold under vacuum to a temperature in the range between about 1000° F. and the temperature of incipient melting of the metallic object section but below the slump temperature of the mold, establishing a temperature level for the treated mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, heating metal to molten state under vacuum, pouring the molten metal into the treated mold to contact and to bond to said metallic element as an appendage while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold untl the cast metal is solidified.

9. The method of forming a composite metallic object comprising producing a refractory mold having a cavity therein of desired form, positioning a solid metallic object consisting of a high temperature high strength alloy selected from the group of cobalt, nickel and iron-base alloys to fill one portion of said cavity, heating the mold under vacuum to a temperature in the range between about 1000° F. and the temperature of incipient melting of the metallic object section but below the slump temperature of the mold, establishing a temperature level for the treated mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, heating metal to molten state under vacuum, pouring the molten metal into the treated mold to contact and to bond to said metallic element while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

10. The method of forming a composite metallic turbine blade comprising producing a refractory mold having a cavity therein in the configuration of a turbine blade, positioning a solid metallic air foil section and a forged metallic root section in the corresponding portions of the mold cavity in a spaced relationship, heating the mold under vacuum to a temperature in the range between about 1000° F. and the temperature of incipient melting of the solid metallic sections but below the slump temperature of the mold, establishing a temperature level for the treated mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, heating metal to molten state under vacuum, pouring the molten metal into the treated mold to contact and to bond to said metallic sections while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

11. The method of forming a composite metallic object comprising producing a refractory mold having a cavity therein of desired form, positioning solid metallic objects of different composition and characteristics in the ends of said cavity of corresponding configuration in a spaced relationship, heating the mold under vacuum to a temperature in the range between about 1000° F. and the temperature of incipient melting of the solid metallic object but below the slump temperature of the mold, establishing a temperature level for the treated mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bonding layer, heating metal to molten state under vacuum, pouring the molten metal into the treated mold to contact and to bond to said metallic element while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

12. A method of forming composite metallic objects comprising heating a refractory mold having a cavity therein and having a metallic core positioned therein to a temperature in the range between 1000° F. and the temperature of incipient melting of the metallic core but below the slump temperature of the mold while the mold is subject to a vacuum of less than 100 microns, establishing a temperature level for the treated mold at which there is a temperature differential in the range between about 200° F. and 2000° F. between the temperature of the treated mold and the temperature of metal to be poured, said temperature differential being of a magnitude effective to prevent excessive diffusion of an element beyond a bond-

ing layer, pouring metal melted under vacuum into the treated mold to contact and to bond to said metallic core while the metal and the mold are maintained under vacuum and maintaining vacuum on said mold until the cast metal is solidified.

References Cited by the Examiner

UNITED STATES PATENTS

1,162,339	11/1915	Coolidge	22—204
1,162,340	11/1915	Coolidge	22—204
1,534,928	4/1925	Dugan	22—203
1,609,747	12/1926	Walter	22—204
1,619,835	3/1927	Summers	29—196.6
1,968,069	7/1934	Chandler	22—204
2,156,998	5/1939	McCullough	22—204
2,309,288	1/1943	Young	22—204
2,709,842	6/1955	Findlay	22—57.2
2,806,271	2/1957	Operhall	266—34
2,817,141	12/1957	Toulmin	29—196.6

2,824,794	2/1958	Hathaway	75—84
2,843,501	7/1958	Ellis et al.	22—204 X
2,862,826	12/1958	Hohn et al.	106—38.23
2,875,483	3/1959	Hughes	22—73
2,895,192	7/1959	Meissner	22—204
2,912,731	11/1959	Brennan	22—209 X
2,974,380	3/1961	Jominy	22—204
3,005,246	10/1961	Murphy et al.	22—216.5
3,060,053	10/1962	Carreker et al.	
3,116,998	1/1964	Pagonis	22—73 X
3,152,373	10/1964	Einthoven et al.	22—204
3,153,824	10/1964	Holmes	22—73 X

FOREIGN PATENTS

10,338	1912	Great Britain.

J. SPENCER OVERHOLSER, *Primary Examiner.*

MICHAEL V. BRINDISI, *Examiner.*

V. K. RISING, *Assistant Examiner.*