METHOD OF SHELL MOLD CASTING

Fig. 1

10. MONO-SHELL MOLD

Preheat to 1900°F

HEAT

Combined Mold and Flask

Preheat to 1900°F

HEAT

Normalise Assembled Shell and Mold

Combined Mold and Flask

Vacuum Chamber

Metal Pouring

CAST METAL MOLD

AIR

Air Cool

Mold - Flask Separation

FLASK

DEBRIS

METAL CASTING

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METHOD OF SHELL MOLDS CASTING


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This invention relates to the art of metal casting to produce precision cast metal parts and it relates more particularly to the art of metal casting, using molds in the form of ceramic shells of relatively thin cross-section, such as in the process described in Patent No. 2,961,751, entitled "Ceramic Metal Casting Process," and referred to in the trade as the "Mono-Shell" process.

The processes of metal casting, using shell molds of the type described, have been subject to a steady sequence of changes intended progressively to improve the molding techniques and the quality and character of the metal castings, that are produced thereby. For the most part, such shell molding processes have been adapted for use in the precision casting of metal parts, such as turbine blades, vanes and the like, used in the power generating means for missiles, aircraft, and automotive vehicles. Such parts are usually fabricated of high alloy steels and metals for high strength at a relatively low cost. Now it is also desirable to produce parts which, in addition to high strength at high temperatures, are characterized by high resistance to thermal shock, that is the ability to withstand rapid changes in temperature over repeated cycles, and it is also a requirement that the process provide castings which are dimensionally accurate and metallurgically sound.

The foregoing are but a few of the essential properties which have been singled out because they represent essential properties, the fuller development of which is a primary concern of this invention. It will be understood that there are many other physical and mechanical properties demanded in the precision cast metal parts and that there are many other parts adapted to be molded by precision casting processes besides turbine blades and vanes, but the invention will be described with reference thereto for purposes of illustration, but not of limitation.

In the precision casting of metal parts with ceramic shell molds, it has been the practice to preheat the mold immediately prior to metal casting for the purpose of insuring complete filling out of the mold with the poured metal to produce solid castings capable of meeting X-ray analysis. When the mold or certain parts thereof is not at proper temperature during metal pouring, premature freezing can sometimes occur, particularly across thin sections of the mold or in remote sections of the mold whereby the poured metal is incapable of flow to fill are parts of the mold. For this purpose, the ceramic shell mold is usually preheated to a temperature on the order of about 1900 °F, for metal pouring. The metal may be heated to a temperature as high as 2700–3000° F. for metal pouring, depending somewhat upon the composition of the metal.

In practice, the preheated shell mold is removed from the preheat furnace for transportation and mounted into position for metal pouring. This sometimes consumes a period of time during which portions of the shell mold cool to a temperature at which difficulties may be experienced in completely filling the mold with the poured metal with the result that the casting is incapable of passing the X-ray test thereby undesirably to increase cost due to scrap. This problem becomes especially significant where the metal cast is of the type of alloy that calls for casting the molten metal in an inert or evacuated atmosphere, in the process referred to as "vacuum casting." Under such circumstances, the preheated shell mold is placed in a sealed chamber to enable evacuation before the molten metal is poured. Evacuation increases the amount of time that the preheated mold is exposed before metal pouring to as much as 30 minutes during which considerably more changes and variation in temperatures can occur with corresponding increase in the difficulty of completely filling the mold and the ability of producing sound castings capable of passing the X-ray test.

In order to minimize heat loss from the time that the mold is removed from the preheat furnace until it is in position for metal pouring, techniques have been developed thermally to insulate the preheated shell mold following removal from the preheat furnace. This operates to minimize heat loss from the preheated shell mold and to minimize temperature differentials between various parts of the shell mold so that, during the metal pouring step, the molten metal will be able to flow more freely into the innermost recesses of the mold completely to fill the mold. Such thermal insulating system has taken on various forms, such as in the use of loose tubular aluminas which is capable of flow to conform to the exterior contour of the shell mold substantially completely to surround the mold. For such purposes, the shell mold is positioned in a receptacle of considerably larger dimension and the space between the shell mold and the walls of the receptacle is filled with loose tubular aluminas or other particulate thermal insulating material to insulate the mold from excessive heat loss while the receptacle housing the shell mold is stationed in position of use, with or without evacuation for metal pouring.

Such systems have been found satisfactory to obviate the problem of heat loss in the preheated shell mold prior to metal pouring but the use of such systems has introduced additional problems in other phases of the metal casting process. In the casting of certain high alloy metals for the production of metal parts wherein high resistance to thermal shock, resistance to bowing and high strength at high temperature are important, it has been found that these properties are incapable of being fully developed when the processes of the type heretofore described are followed in the practice of the metal casting. This is particularly true in the casting of metal alloys such as are formulated in accordance with the teachings of the preceding application Ser. No. 68,616, filed November 14, 1960, entitled "Alloy Composition and Products Produced Therefrom," and now abandoned, or the type of alloy marketed under the trade name SM-302 of Sierra Metal.

It is an object of this invention to provide a method and means for shell mold casting wherein the mold cavity can be properly filled during metal pouring to produce X-ray sound castings and wherein the metal casting produced is characterized by high strength at high temperature, high resistance to heat shock and resistance to bowing in use.

More specifically, it is an object of this invention to produce a new and improved method and means for metal casting using shell molds to produce parts having improved mechanical and physical properties.

These and other objects and advantages of this inven-
tion will hereinafter appear and for purposes of illustration, but not of limitation, an embodiment of the invention shown in the accompanying drawing, in which—

FIG. 1 is a flow diagram of the process embodying the features of this invention; and

FIG. 2 is a schematic sectional elevational view of a thermally insulated flask adapted for use in the practice of this invention.

The invention will hereinafter be described with reference to the process of vacuum melting of an alloy steel of the type wherein high resistance to thermal shock and high strength at high temperature as well as resistance to bowing are enhanced by rapid cooling, but it will be understood that the concepts of the invention are applicable to casting techniques wherein the metal is poured into the shell mold with or without vacuum and with other metals which are benefited by rapid cooling from pouring temperature.

Referring first to FIG. 2 of the drawing, the numeral 10 is intended to designate a Mono-Shell mold formed in accordance with the practice of the previously mentioned patent by the alternate application of a dip coat composition and layers of stucco on a pattern of heat disposable material which is removed from the build-up ceramic shell by a subsequent firing step. The formed ceramic shell is complete with runners and spout 12 into which the molten metal is adapted to be poured for passage through the runners into the mold cavities formerly occupied by the pattern before removal. After firing the built-up layers of ceramic, dip and stucco coats, a shell mold of sufficient strength and integrity is secured to enable handling in the usual manner for preheating and metal pouring without investment or back-up of the type used in the conventional methods for investment casting. However, it is because of this thin shell that rapid heat transfer to and from the mold becomes possible to raise some of the problems faced by this invention.

Certain alloys exhibit their best strength and resistance to thermal shock when rapidly cooled immediately after casting into the mold. For this purpose it has been found desirable to free the mold of the insulation in the attempt to take advantage of the high heat transfer permissible through the relatively thin walls of the ceramic shell into which the molten metal is cast. Because of the intricate shapes of the ceramic shell molds, satisfactory removal of the loose refractory back-up or insulating material is difficult to achieve and the insulation material also tends to bond to the surfaces of the mold with the result that it is difficult to obtain uniform and optimum cooling rates. Thus tubular or granular insulating materials tend to compact about the shell and to stick to the mold with the result that uniform conditions for cooling cannot be maintained and an inferior product often results.

It is a concept of this invention to provide a method and means for thermal insulation of the mold from the time that it is removed from the preheated furnace until the metal is poured in the mold while still leaving the mold free for cooling at whatever rate is desired. This has been accomplished in accordance with the practice of this invention by the enclosure of the preheated shell mold in a preheated insulating liner which is not in contact with the mold but still offers sufficient insulation to minimize heat loss during the time delay from preheating to metal pouring and which can be completely and cleanly separated from the liner either by removal of the mold from the liner or by removal of the liner from the mold to permit rapid and uniform cooling of the cast metal immediately after metal pouring.

Illustration is made of a thermal insulating device of the type adapted for use with a shell mold comprising an inner liner 20 of alloy metal or other structurally strong material which is stable under the temperature and atmospheric conditions to which it is adapted to be exposed in use with the ceramic shell mold in metal casting. The inner liner is adapted to be open at the top and preferably, but not necessarily, also open at the bottom and it is dimensioned to define an interior space which is larger than the crosswise and lengthwise dimensions of the shell mold to enable the shell mold to be received therein with a minimum space between the outer wall of the mold and the metal lining, and which is dimensioned to have a height, depending upon the position of the bottom wall, which is less than the height of the ceramic shell mold but greater than the height of the mold from the base to the pouring spout, so that at least a portion of the spout 12 will project beyond the open end at the top of the inner lining member.

Preferably, though not necessarily, shaped to correspond with the lining and spaced outwardly therefrom is an outer flask 22 of a thermally stable, structurally strong material which is also open at the top but which is formed with a bottom wall 24 to define a housing in which the liner 20 is adapted to be received. The space between the liner and the flask is adapted to be provided with thermal insulating material 26 which may extend from the upper edge of the flask to the bottom wall but preferably terminates short of the flow line, as illustrated in FIG. 2.

In the preferred practice of this invention, the layer 28 of thermal insulating material on the bottom of the flask and adapted to extend upwardly into the area between the liner is formed of a loose thermal insulating material such as tabular alumina, diatomaceous earth, exfoliated vermiculite, bloated clay, first brick or other ceramic chips or the like whereby the thickness of the bottom layer 28 of the bottom layer 28 can be varied to raise or lower the level at the upper surface of the bottom wall for the liner by an amount depending upon the height of the shell mold that the mold to rest on the surface of the bottom wall while the portion or the pouring spout 12 extends upwardly through the open end of the flask. Thus the height of the cavity in the insulation flask can be varied for use of the flask with various molds. However, when use is made of a shell mold of uniform dimension over a large number of cycles, such variation in height may not be necessary such that the bottom layer of thermal insulating material may be formed of a rigid material of predetermined dimension. Alternatively, a combination of insulation of fixed dimension coupled with loose thermal insulating material may be employed. In such a case, introduction of such loose material can be undertaken in amounts to build up the height of the bottom wall and to provide an increasing decrease of the height of the cavity for use with molds of smaller dimension. Removal of insulation material to achieve the opposite effect for increasing the depth of the cavity for use with molds of greater height is also contemplated.

The insulation disposed between the inner sleeve and the outer flask can be built up with refractory brick to become a permanent part of a prefabricated structure or use can be made of insulation such as loose refractory grains, castable refractory, ceramic beads, foamed ceramics, tabular alumina, or the like.

Referring now to the flow diagram for a description of the process embodying the features of this invention, it is desirable to preheat both the mono-shell mold 10 and the insulating flask 30 in which the preheated mold is adapted to be received. Because the mono-shell mold and the flask usually differ in the amount of mass and therefore require different times for heating to a desired preheat temperature, such as for example 1900° F., the shell molds and the flasks are preheated in separate furnaces 32 and 34.

After the separate units are brought up to temperature and prior to metal pouring, a mono-shell mold 10 and flask 30 are removed from their furnaces and the shell mold is inserted into the lining of the preheated flask and then the open end of the flask is covered with a split insulating disc 36 provided with a central opening to fit about the pouring spout which extends outwardly through
the top of the flask and the mouth of the mold is also closed, preferably prior to preheat, with a ceramic cover to protect the interior of the mold from materials which may contaminate the mold cavity and constitute an impurity in the metal casting. The assembled shell mold and the insulation flask are returned to a preheating furnace to normalize the temperature of the elements or otherwise to bring the elements to uniform preheat temperature prior to metal casting.

When the temperature of the elements has been stabilized, as at a preheat temperature of about 1900° F., the flask with the shell mounted therein is removed from the furnace and placed in position for metal pouring in the vacuum chamber of the vacuum molding machine. The chamber is sealed and the vacuum is drawn, all of which may take from 5 to 30 minutes from the time that the flask and mold are removed from the preheated furnace.

When the desired vacuum conditions have been achieved in the vacuum chamber, the metal which has in the meantime been reduced to molten state in a melting furnace located above the vacuum chamber is poured into the open mold cavity of the mold to fill the mold cavity which, by reason of the insulation flask, has retained sufficient temperature in uniform distribution to enable rapid flow of the molten metal to fill the innermost recesses of the mold cavity. As soon as the metal has been poured and hot, the vacuum is released, and the flask is opened and the flask is removed. The shell mold is lifted from the flask to enable rapid cooling outside of the flask.

The objective is to achieve as rapid cooling as possible of the cast metal in the mold. For this purpose, the shell mold is removed from the flask and; for the heating of the shell from the heated flask, the cast metal can advantageously be further accelerated with the application of a coolant, such as air or other fluid onto the surfaces of the shell mold rapidly to conduct heat away from the thin walls of the shell mold—whereby the cast metal is more rapidly reduced in temperature with a corresponding increase in the resistance to thermal shock, resistance to bow, and maximizing the development of high strength at high temperature.

It has been found that resistance to thermal shock and resistance to bowing of turbine blades or vanes cast of SM-302 alloy or alloys of the type described in the aforementioned copending application can be increased by more than 50 and up to 500% by the shell mold is removed after metal casting rapidly to reduce the temperature of the cast metal as compared to metal parts cast of the same metal and by the same process with the exception that the cast metal is allowed to cool in the shell while retained in the insulation flask.

Thus, when a shell mold is properly handled to take advantage of the thin wall sections which permit high heat transfer, numerous improvements can be achieved in shell molding which have not been available in other processes for precision casting. For example, in the preparation of the shell mold, it has been found that the rapid heat transfer through the thin walls of the ceramic shell enables the removal of the wax pattern in a much more simplified and rapid manner without danger of mold destruction since the assembly can be introduced into a furnace heated to high temperature whereby the high heat transfers sufficiently rapidly through the ceramic walls of the shell to reduce surface portions of the wax pattern to molten state before the remainder of the pattern is heated to such elevated temperature as to cause expansion. Thus, before the remainder of the pattern is heated to elevated temperature, sufficient of the surface portion has already been melted away because of the high rate of the transfer of heat through the shell so that space is made available into which the pattern may later expand.

This invention now takes further advantage of the reverse heat flow in that relatively high heat conductivity through the relatively thin walls of the shell mold enables removal of the metal shell from the insulation flask and removal of heat from the cast metal sufficiently rapidly to take advantage of the excellent thermal shock resistance, resistance to bowing, and the development of increased strength at high temperature which can be achieved when certain of the cast alloy metals are cooled as rapidly as possible.

The described process can also be adapted for stress relieving or heat treatment of the cast metal since the mold can be removed from the insulation flask after the metal has been poured for insertion into a suitable heat treat furnace or stress relieving furnace with a minimum of time delay, without insulation particles adhering to the surface and for maximizing the temperature effect for heat treatment or stress relieving to which the cast metal is exposed.

It will be understood that changes may be made in the details of the construction of the insulation flask or in the method of handling the elements and the materials in the process described, without departing from the spirit of the invention, especially as defined in the following claims.

We claim:

1. In the process of metal casting with shell molds having ceramic walls of relatively thin cross-section for heat transfer therethrough at a relatively high rate, the steps of preheating the shell mold, preheating an insulation flask having an open top in communication with a central opening and control openings having diameters greater than the crosswise dimensions of the shell mold and a depth slightly less than the overall depth of the shell mold, inserting the preheated shell mold into the preheated insulation flask, transferring the preheated flask with the preheated shell mold therein to the position for metal pouring, pouring the molten metal into the preheated shell mold while in the preheated insulation flask, separating the shell mold and the insulation flask after the metal has been poured, and cooling the metal cast in the shell mold while the mold is outside of the insulation flask for more rapid removal of heat from the metal cast in the mold.

2. The process as claimed in claim 1 which includes the step of heating the preheated flask with the preheated shell mold therein for stabilizing the temperatures thereof prior to transfer for metal pouring.

3. The process as claimed in claim 1 which includes the step of covering the insulation flask after the shell mold has been inserted but with a portion of the shell mold for metal pouring extending upwardly beyond the cover.

4. The process as claimed in claim 1 in which the preheated shell mold and the preheated insulation flask are positioned in a vacuum chamber for metal pouring upon removal from the preheated furnaces which includes the step of drawing a vacuum on the chamber prior to metal pouring.

5. The process as claimed in claim 1 in which includes the step of covering the exterior surface of the shell mold after removal from the insulation flask with a coolant to accelerate the removal of heat from the walls of the shell mold.

6. In the process of casting high alloy metals characterized by high strength at high temperatures and high resistance to thermal shock wherein the metals are cast with a shell mold having ceramic walls of relatively thin cross section for heat transfer therethrough at a relatively high rate, the steps of preheating the shell mold, preheating an insulation flask having an open top in communication with a central opening having crosswise dimensions greater than the crosswise dimensions of the shell mold and a depth slightly less than the overall depth of the shell mold, inserting the preheated shell mold into the preheated insulation flask, transferring the preheated flask with the preheated shell mold therein to the position for metal pouring, pouring the molten metal into the preheated shell mold while in the preheated insulation flask,
separating the shell mold and the insulation flask after the metal has been poured, and cooling the metal cast in the shell mold while the mold is outside of the insulation flask for more rapid removal of heat from the metal cast in the mold.

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