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PRECISION CASTING MOLDS AND TECHNIQUES

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This invention relates generally to the art of investment casting, and more specifically to improvements in techniques and molds for the precision casting of steels.

A common problem heretofore existing in the investment casting industry has been the production of steel castings having a high quality, as-cast surface finish. In particular, certain investment-cast steels are recognized to be subject to a condition of surface pitting which has been a major cause of rejected castings. This condition of surface pitting is frequently referred to as "chrome pitting," since all of the Type 400 series of stainless steels are considered to be prone to pitting to at least some degree. The condition is particularly severe on Type 410 and Type 416 stainless steel, and in the case of Type 410 martensitic stainless steel, is specifically called "410 pitting."

As is known to those familiar with this problem, the pitting condition often takes the form of circular pits up to 1/32 of an inch or larger in diameter. Sometimes individual pits are separated by 1/8 to 1/4 of an inch of smooth surface, while other times the pits are so close together that the entire surface of the casting appears to be rough. Generally, however, the pits are larger and deeper when less numerous, and tend to be shallower and smaller when closer together. Both types of pitting may be found on different parts of the same casting.

The mechanism of the attack producing pitting is not completely understood, although it is believed to be a metal/mold reaction which occurs after solidification. This reaction has been shown to be very temperature dependent. Thus, with alloys such as Types 420 and 440, which have only a minor tendency toward 410 pitting, the condition can usually be controlled by avoiding excessive temperatures during casting. With Types 410 and 416, however, additional action must be taken to avoid surface pitting.

Because of the fact that the cause or causes of surface pitting are not completely understood, many different techniques and theories have been advanced in the past in attempts to cope with this problem. One of the most common practices of the art has been to add halogenated hydrocarbons to the hot mold cavity immediately prior to casting. Liquids such as trichloroethylene, chloroethane and carbon tetrachloride are usually employed for this purpose, although solid materials, such as Teflon turnings, also have been used. It has been presumed that the vaporization and partial combustion of these materials produced a reducing atmosphere inside the mold cavity which inhibited the metal/mold pitting reaction.

This conventional method is only partially successful and is difficult to control. If an insufficient quantity of the "inhibitor" is used, or if too long a period elapses between the time of its addition to the mold cavity and the pouring of the metal so that the material burns up or escapes, the desired effect is not obtained. On the other hand, if too much inhibitor is added, there is the danger that the material will not vaporize before pouring and that gas will be entrapped in the casting. Further, where the mold shape is complicated, it is difficult to obtain a uniform distribution of the inhibitor throughout the mold cavity.

The conventional method described above has other inherent disadvantages. It involves an extra operation by the caster at the very moment when he is busy with

other matters. Where it is necessary to apply a partial vacuum around the mold to facilitate the filling of narrow passages, the vacuum tends to draw out the inhibitor through the pores of the mold before the metal is poured. Finally, the combustion of the halogen compounds produces vapors which are annoying and, in some instances, poisonous. For example, phosgene may be formed from carbon tetrachloride, trichloroethylene, and the like.

An object of the present invention is to provide precision casting techniques and molds for maintaining a high surface quality throughout the range of steel casting alloys.

A more specific object of the invention is to provide precision casting techniques and molds which substantially eliminate the condition of surface pitting heretofore encountered with many investment-cast alloys.

Another object of the invention is to provide precision casting techniques having the advantages described above which can be carried out in a simple, inexpensive, and expeditious manner.

A further object of the invention is to provide techniques for substantially eliminating surfaces pitting of investment-cast steel which are compatible with known ceramic shell molding techniques of precision casting and which permit the use of the usual shell refractories.

A growing trend in the investment casting industry is to use ceramic shell molds in place of the conventional bulky investment molds, and the present invention is particularly adapted to this modern shell molding technique of precision casting. Although the shell molding process requires very little in the way of description to those skilled in the art, in order to provide a full and complete disclosure to the present invention and its advantages, the following brief summary of this process is believed to be in order.

Shell molds are usually prepared by dipping a disposable pattern, which is a replica of the part to be cast, including the necessary gates and risers, into a refractory slurry consisting essentially of a suspension of a fine refractory powder in a suitable bonding liquid. The binder is one which is capable of hardening during drying at room conditions. After dipping, the excess slurry is drained from the coated pattern and the slurry coating is sanded or stuccoed with coarser refractory particles. This process of dipping and stuccoing is repeated until a refractory shell having a sufficient thickness to resist the stresses occuring in subsequent operations is built up around the pattern. The usual thickness of the shell is from 1/8 of an inch to 1/2 of an inch, although thinner or heavier shells may be formed for special situations. The disposable pattern is subsequently removed from the shell mold and the mold prepared for the casting operation.

The disposable patterns are customarily formed from a combustible material, such as wax or a synthetic resin. In the case of wax patterns, a procedure commonly known as "flash dewaxing" is employed to remove the pattern material from the shell mold. According to this procedure, the shell is placed in a furnace at an elevated temperature, as, for example, from 1600° F. to 1800° F. Under these conditions, a rapid heat transfer occurs through the shell so that a surface skin of wax melts before the bulk of the wax heats up enough to expand and crack the shell. As the bulk of the wax does heat up, the molten surface material either flows out of the mold or soaks through the shell. This provides a space to accommodate the subsequent expansion of the bulk of wax so that it will not crack the shell.

Disposable patterns formed of synthetic resins can be successfully removed from shell molds by initially softening the pattern material with a suitable synthetic resin

solvent. Thereafter, the shell mold is heated in an oxidizing atmosphere to drive off the last vestiges of the pattern material and to prepare the mold to receive the molten metal.

According to the present invention, the shell mold is provided with a graphite coating after the shell has been burned out sufficiently to receive the molten metal and has been cooled to around room temperature. This is preferably accomplished by dip coating the mold shell in a suitable slurry and then stuccoing the slurry coating while still wet with particles of coarse graphite. The slurry should be capable of setting at room temperature to form a coating for holding the graphite and should not disintegrate at the pouring temperature of the metal. The slurry which is used may, if desired, be the refractory slurry that is used to build up the mold shell in the manner described above.

After the final coating has dried, the shell mold is heated to the desired temperature for preparing the mold for casting. The firing of the mold is carried out in an atmosphere which is sufficiently reducing in nature so as to prevent the graphite from burning off. When sufficiently heated, the shell mold is then removed from the furnace and cast in air in the usual manner.

It is believed that, as the molten metal fills the mold, the intense heat causes a rapid combustion of the graphite which uses up the local oxygen and blankets the shell with a reducing atmosphere. This reducing atmosphere inhibits the metal/mold reaction until the temperature falls low enough that there is no further tendency toward pitting. Production size castings of Type 410 stainless steel have been made by this technique which were completely free of "chrome pitting," while identical castings made from the same melt at the same time and in conventional mold shells were so pitted that they had to be rejected as not meeting the surface requirements for investment castings.

In almost all instances, a single application of the graphite is sufficient. However, more than one refractory coating may be applied and stuccoed with graphite, if desired. In addition to substantially eliminating the condition of surface pitting, the extra graphite coating or coatings has the added advantage of sealing up any cracks which might have formed in the shell during the elimination of the disposable pattern material.

When only an occasional shell mold is being processed by the technique of the present invention, the required reducing atmosphere in which the mold is fired can be obtained conveniently by placing the graphite-stuccoed shell on a refractory slab and sprinkling additional coarse graphite around the mold. A suitable cover may be then positioned over the mold shell and the loose graphite and the entire assembly placed into an ordinary furnace. When production quantities of shells are to be cast, it is preferred to provide a furnace which is capable of maintaining a suitable reducing atmosphere at the desired temperatures.

Specific examples of the process contemplated by the invention are given below:

A pattern assembly of 48 polystyrene patterns mounted on a hollow, cylindrical wax tree was prepared. Six coats of refractory were applied to the pattern assembly by dipping it into a slurry formed of three parts zircon powder and two parts fused silica powder suspended in a bonding liquid consisting essentially of a colloidal silica sol, a small amount of an organic film former, and minor amounts of a wetting and defoaming agent. The first two refractory coatings were stuccoed with granular zircon and the remaining coatings with a coarse fire clay grog.

The refractory coatings were dried one hour between individual dips. After drying, the first two coatings were impregnated with zirconium acetate in the manner described in my copending application Serial No. 152,241, filed November 14, 1961, and entitled "Precision Casting Materials and Techniques." Each application of the zirconium acetate was allowed to harden to form a glass-like, substantially solvent-proof barrier film.

The plastic patterns and part of the wax tree were removed by soaking the mold in a bath of trichloroethylene. After the plastic patterns had been substantially completely dissolved, the mold shell was removed from the solvent bath and fired in an oxidizing atmosphere to 2000° F. to remove the balance of the wax and plastic and to effect a complete burn-out of the shell.

The shell was then cooled and given one additional coating of the refractory slurry. The wet slurry coating was stuccoed with coarse graphite identified as No. 8 Mexican Graphite, sold by The United States Graphite Company. The particle size distribution of the graphite was as follows:

U.S. Standard Sieve No.:	Percent retained
10	25.0
30	70.3
40	1.8
100	0.9
325	0.6
Passing 325	1.3

After the final graphite-stuccoed coating had dried, the shell was placed on a refractory slab, approximately one-half pound of loose graphite was sprinkled around the shell, and a heat-resistant metal can was placed over the shell and the graphite. The entire assembly was placed in an ordinary burn-out furnace at 2000° F. for one hour. The shell was removed and placed in a casting chamber and 20¼ pounds of Type 410 stainless steel at 2975° F. were poured into the shell. A suction of two inches Hg was applied to the shell during pouring to facilitate filling. The suction was removed as soon as the pour was complete and the casting was allowed to solidify and cool in air.

During cooling, the graphite was observed to burn as long as the shell was red hot. After cooling, the shell was removed in a molten salt bath and the casting sand-blasted to reveal an excellent as-cast surface with no pitting on either the castings or the tree. A similar shell, but without the graphite was poured at the same time from the same melt and was so badly pitted that the castings were not acceptable.

Numerous additional shells, formed on both wax and plastic patterns, were processed by the technique of the invention. The wax patterns did not require the zirconium acetate impregnation and were removed directly by a flash burnout at 2000° F. The atmosphere for preheating the shells was attained by adjusting the gas/air ratio of a normal burnout furnace until the flame was "sooty." Under these conditions the gas was incompletely combusted, as evidenced by the fact that the gases escaping through the cracks around the door and through other parts of the furnace continued to burn, a condition not encountered in the normal (oxidizing) operation of the furnace. In all cases, the castings were free of 410 pitting.

As explained above, the graphite-stuccoed coating on the shell mold can be attained by simply dipping the shell in the usual refractory slurry and stuccoing the slurry while wet with the graphite. Thus, the invention will be seen to be readily compatible with known shell mold techniques and with the usual shell refractories, such as silica, zircon, alumina, and so forth. Another very important advantage is that the process of the invention does not require any special steps at the time the melt is to be poured. Instead, the molds are cast in the usual manner.

It will also be seen that the method provided by the invention is substantially "fool-proof" and is very easy to control. Still further, the desired effect of producing a reducing atmosphere during solidification of the casting

is obtained regardless of the complexity of the mold shape.

Many modifications and variations of the invention will be apparent to those skilled in the art in view of the foregoing detailed disclosure. Therefore, it is to be understood that, within the scope of the appended claims, the invention can be practiced otherwise than as specifically shown and described.

What is claimed is:

1. In a process of investment casting, the steps of forming a refractory mold suitable for precision casting metal, said mold having a pattern cavity, providing said mold with a coating layer of a combustible, deoxidizing agent, said coating layer being provided only externally of said pattern cavity, said cavity and the inner layer of said mold defining said cavity being free of deoxidizing agent, firing said mold in a reducing atmosphere to prepare said mold for casting, effecting combustion of said deoxidizing agent to produce a reducing atmosphere, and air-casting metal into said mold while protected by the reducing atmosphere produced by the burning deoxidizing agent.

2. In a process of investment casting, the steps of forming around a combustible, disposable pattern a refractory mold suitable for precision casting metal, removing said pattern from said mold to form a pattern cavity, said step of removing said pattern including heating said mold in an oxidizing atmosphere to burn out said pattern cavity, thereafter coating said mold only externally of said cavity with a deoxidizing agent, said cavity and the inner layer of said mold defining said cavity being free of deoxidizing agent, firing said mold to prepare it for casting, effecting combustion of said deoxidizing agent to produce a reducing atmosphere, and air-casting metal into said mold while protected by the reducing atmosphere produced by the burning deoxidizing agent.

3. In a process of precision casting, the steps of forming a shell mold having a pattern cavity, coating said shell mold with a slurry, stuccoing said slurry coating while wet with a deoxidizing agent, said deoxidizing agent being provided only externally of said cavity, said cavity and the inner layer of said mold defining said cavity being free of deoxidizing agent, drying said stuccoed coating, heating said mold in a reducing atmosphere to prepare it for casting, effecting combustion of said deoxidizing agent to produce a reducing atmosphere, and air-casting metal into said mold while protected by the reducing atmosphere produced by the burning deoxidizing agent, said metal being cast while said mold is at a temperature above the combustion temperature of said agent.

4. In a process of precision casting, the steps of forming a shell mold around a combustible, disposable pattern, removing said pattern from said mold to form a pattern cavity, said step of removing said pattern including heating said mold in an oxidizing atmosphere to burn out said pattern cavity, coating said mold with a slurry, stuccoing said slurry coating while wet with a solid, deoxidizing agent, said deoxidizing agent being applied only externally of said cavity, said cavity and the inner layer of said mold defining said cavity being free of deoxidizing agent, firing said mold in a reducing atmosphere to prepare it for casting, effecting combustion of said deoxidizing agent to produce a reducing atmosphere, and air casting metal into said mold while protected by the reducing atmosphere produced by the burning deoxidizing agent.

5. In a method of precision casting, the steps of preparing a disposable pattern, coating said pattern with a refractory slurry, applying a stuccoing material to said slurry coating to form a refractory shell layer, repeating said dipping and stuccoing steps to build up a shell mold, removing said pattern from said mold to form a mold cavity, applying another external coating of said refractory slurry to said mold, stuccoing said another coating with relatively coarse particles of graphite, said graphite being applied to said mold only externally of said cavity, said cavity and the inner layer of said mold defining said cavity being free of deoxidizing agent and of said graphite, firing said mold in a reducing atmosphere to prepare it for casting, effecting combustion of said graphite to produce a reducing atmosphere, and air-casting stainless steel into said mold while protected by the reducing atmosphere produced by the burning graphite.

6. A method of precision casting steel comprising the steps of providing a disposable pattern formed of a combustible material, forming a refractory shell mold around said pattern, removing said pattern from said mold to form a pattern cavity, said step of removing said pattern including heating said mold in an oxidizing atmosphere to burn out said mold, coating said mold only externally of said cavity with graphite, said cavity and the inner layer of said mold defining said cavity being free of deoxidizing agent and of said graphite, heating said mold in a reducing atmosphere to a temperatture of about 2000° F., effecting combustion of said graphite to produce a reducing atmosphere, and air-casting metal into said mold while protected by the reducing atmosphere produced by the burning graphite.

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