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PROCESS OF PREPARING PRECISION CASTINGS

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Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

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This invention relates to a mold structure containing a shell mold and to an improved process of preparing same and is a continuation in part of application Ser. No. 7,633, filed on February 22, 1948. It also relates to improved processes of preparing precision castings.

At the present time there is a demand for a satisfactory method of casting metal objects that are complicated in shape or are expensive to produce by machining operations. A commercial method that has heretofore been utilized for producing precision castings is the Lost-wax method. In such method a plastic pattern, such as wax, is placed in a flask and a relatively large mass of investment material is poured into the flask surrounding the pattern. The investment material is permitted to set and the mold with the pattern in place is heated to a temperature sufficient to liquefy the pattern material which is then poured from the mold to provide a cavity into which molten metal is cast.

In the Lost-wax method of preparing precision castings, however, the mold produced from the wax pattern must be made relatively thick to resist strains caused by the initial expansion of the wax during heating to remove it from the investment material to form the mold and because the overall expansion of the wax increases as the size of the pattern of the object to be cast is increased, it is impractical to prepare large castings by the Lost-wax method because of the thick mass of refractory material that must be utilized to resist the strains caused by the expansion of the wax which must be heated to a temperature sufficient to liquefy the wax. It is also impractical to prepare precision castings in such molds having portions, such as thin walls, inserts, or cores, which must yield to prevent cracks from forming in the casting when molten metal which is cast into the mold contracts about such portions during cooling.

Because of the thickness of the investment material which must be utilized in preparing molds by the Lost-wax method, it is also difficult to produce precision castings in such molds that have uniformly smooth surfaces, sharp corners, and well-defined inserts when the metal to be cast has a high fusion temperature, such as approximately 1850° centigrade or more. This is due to the fact that the investment material utilized in such molds has poor heat conducting properties, and when the molten metal is cast into the cavity of the mold at such temperatures, it causes an expansion of the investment material in the inner surface layer of the mold to a greater extent than the remainder of the mold, thereby causing the inner cavity-forming surface of the mold to crack and deform. In the Lost-wax method, difficulty is also encountered and much time is consumed in removing the relatively large mass of investment material from the casting formed in the mold cavity which increases the cost of preparing the castings.

According to the present invention, an improved shell mold is provided by applying a composition in the form of a slurry to a frozen mercury pattern in the form of one or more films or layers to provide a coating which dries at low temperatures. The coated frozen mercury pattern is then suspended in a flask and a refractory material in the form of small particles is provided for absorbing residual liquid carrier in the coating that has not vaporized and for supporting the shell mold during the liquefaction and removal of the frozen mercury pattern and during the casting of metal into the shell mold. Because the shell mold is supported by the refractory particles during the removal of the frozen mercury pattern and the casting of molten metal therein, the coating applied to the frozen mercury pattern to provide the shell mold may be comparatively thin. For instance, simple shell molds having an average thickness of \( \frac{1}{4} \) to \( \frac{1}{8} \) of an inch may be utilized in the present process and even when the frozen mercury pattern is of considerable size, the average thickness of the shell mold need not be greater than \( \frac{1}{4} \) to \( \frac{3}{8} \) of an inch in thickness, and for large patterns, the average thickness of the shell mold need not be greater than \( \frac{3}{8} \) to \( \frac{1}{2} \) of an inch.

In utilizing the mold structure of the present invention, the process of forming the shell mold when a metal having a high fusion point is to be cast into the shell mold, may also be combined with the process of casting the metal into the shell mold. In preparing shell molds into which metal having a high fusion point is to be cast, it is necessary unless the shell mold is precooled to a low temperature, to provide in the shell mold a binder that is capable of resisting the temperature of the casting metal. In such cases, the coating composition applied to the frozen mercury pattern contains not only a low temperature binder but also contains a binder that becomes effective at raised temperatures and which after becoming effective is capable of resisting metal having a high fusion point which is to be cast into the shell mold. According to the present invention the mold structure, including the flask, shell mold, and the refractory particles between the flask and the shell mold, is heated to a sufficiently high temperature to cause the
raised temperature binder to become effective as a binder for the refractory material in the shell mold and to modify the low temperature binder to provide vapors for producing a porous shell mold, and molten metal is then cast into the shell mold while it is still hot.

The present invention also contemplates providing a mold structure in which the shell mold is supported in place by refractory material bonded together by a frozen material and in preparing precision castings by casting metal into molds while the shell mold is at low temperatures.

It is therefore an object of the present invention to provide an improved mold structure and the process of preparing it including an outer flask, a shell mold, and refractory material in the form of small particles for supporting the shell mold.

Another object of the present invention is to provide an improved mold structure, including a shell mold, an outer flask, and loose refractory particles having irregular surfaces interposed between the shell mold and the flask which refractory particles resist displacement relative to each other but are capable of yielding when molten metal is cast into the shell mold.

A further object of the invention is to provide an improved process of preparing a mold structure containing a shell mold for use in preparing precision castings in which a refractory material in the form of loose particles is provided to absorb any residual liquid carrier remaining in the coated pattern after the drying process and which also serves as a support for the coated pattern during the liquefaction and removal of the frozen mercury therefrom and for the shell mold during the casting of a molten material therein.

Another object of the present invention is to provide an improved process of preparing precision castings in which a shell mold containing refractory particles, a low temperature binder, and a raised temperature binder, is supported in casting position and is heated to a sufficient temperature to cause the raised temperature binder to become effective as a binder for the refractory particles and the low temperature binder to provide vapors for producing a porous shell mold and in which metal is cast into the shell mold while the shell mold is still in its heated state.

A further object of the invention is to provide an improved process of preparing precision castings in which metal is cast into a shell mold while the shell mold is at temperatures substantially below 0° centigrade.

Still further object of the present invention is to provide an improved process of preparing precision castings in which a shell mold is supported by refractory particles and metal is cast into the shell mold while the mold is at low temperatures.

The patent will be better understood by reference to the accompanying drawings in which:

Fig. 2 is a cross sectional view of the frozen mercury pattern and a supporting rod for the frozen mercury pattern;

Fig. 3 is a cross sectional view of the frozen mercury pattern taken on a plane passing through line 2—2 of Fig. 1;

Fig. 4 is a cross sectional view of a mold structure, including an outer flask, the coated frozen mercury pattern shown in Fig. 3, and refractory particles interposed between the flask and the coated pattern;

Fig. 5 is a cross sectional view on the line 6—6 of Fig. 4; and

Fig. 6 is a view similar to that shown in Fig. 5 with the frozen mercury pattern removed and a precision casting formed in the mold cavity.

In preparing the mold structure of the present invention, a frozen mercury pattern of the object to be cast is utilized in preparing a shell mold. For purposes of illustration, a frozen mercury pattern is shown in Fig. 1, a section of which as shown in Fig. 2 is in the form of a vase having an arcuate-shaped portion 1 terminating in an apex 2 forming a hollow interior portion 3 which extends substantially the entire length of the pattern. As shown in Figs. 1 and 3, the frozen mercury pattern is provided adjacent its upper portion with an opening 4 and terminates in an upwardly extending sprue 5. The frozen mercury pattern may be formed in a parting line 6 of any suitable material, such as metal, and during the freezing of the mercury, one end of a rod 7 provided with a suitable handle 8 may be frozen in the mercury pattern to facilitate the manipulation of the frozen mercury pattern during application of the coating to form a shell mold.

In preparing the shell mold, a coating composition is utilized which is in the form of a slurry at temperatures below −40° centigrade, which is the freezing point of mercury, and contains a refractory material in a finely divided state in proportions constituting a predominant amount of the solid ingredients of the composition which form the applied coating after the liquid carrier volatilizes. The refractory material may, for instance, constitute approximately 95% or more of the solid ingredients of the applied coating. The composition must also contain a low temperature binder for the refractory particles which is effective in binding and which is present in an amount sufficient to bind the refractory particles together and to the frozen mercury pattern. The low temperature binder must also be thermostable and must be present in an amount sufficient to bind the refractory particles together at temperatures ranging from below −40° centigrade up to at least normal room temperatures. The composition may also contain a raised temperature binder which becomes effective as a binder for the refractory particles at intermediate high temperatures and which after becoming effective acts as a binder for the refractory particles and is present in an amount sufficient to bind the refractory particles together over a temperature range from low temperatures up to a temperature sufficient to resist metal cast into the shell mold at temperatures of approximately 1800° centigrade or higher. When a raised temperature binder is present, the low temperature binder must be effective at a temperature and must be present in an amount sufficient to bind the refractory particles and the raised temperature binder to the frozen mercury pattern and the refractory particles and the raised temperature binder together until the raised temperature binder becomes effective in binding the refractory particles of the mold and to provide a porous shell mold the low temperature binder should be capable of volatilizing, decomposing and volatilizing, or becoming otherwise modified to form vapors for producing a porous
shell mold when the shell mold is heated to temperatures above that at which the raised temperature binder becomes effective in binding the refractory particles. The composition also includes a liquid carrier for the refractory particles and the binder or binders which liquid carrier is present in an amount sufficient to provide a slurry of sufficiently low viscosity to enable the composition to be applied as a coating over the refractory particles. The carrier must be in the liquid state at temperatures below the freezing point of mercury and should be capable of volatilizing at temperatures below \(-40^\circ\) centigrade in a relatively short period of time. Liquids having a boiling point below normal room temperatures, such as below \(20^\circ\) centigrade, are satisfactory, although it is more desirable to provide a liquid carrier that is in the gaseous state at normal room temperature and which has a boiling point below \(0^\circ\) centigrade. A liquid may be provided that is a solvent or a partial solvent for the low temperature binder through the invention is not to be limited in this respect. As the refractory material, any suitable material may be utilized that is capable of resisting high temperatures and which may be prepared in a finely divided state, such as silica, zirconia, zirconium silicate, magnesium oxide, chromite, alumina, ground quartz, graphite, flipt, silicon carbide, an aluminum silicate, such as sillimanite, or a mixture of two or more of such materials, or a mixture of magnesium oxide and calcium oxide may be employed. In preparing most shell molds, a slurry material, such as silica or zirconium silicate, or a combination of silica and zirconium silicate, is desirable.

In preparing a slurry for application as films or layers to the frozen mercury pattern to build up a shell mold, the refractory material utilized should be of a sufficiently fine texture so that when metal is cast into the shell mold, a casting having a smooth surface will be obtained. The particular size of the refractory material, however, may be varied and will depend upon the size and intricacy of the castings to be produced as well as being adapted to the metal to be cast and to its surface. For instance, particles passing through a screen of 60 meshes per square inch may be utilized. Extremely fine particles, such as particles passing through a 1000 mesh screen, however, adversely affect the porosity of the mold in which they are utilized and are not necessary in providing a smooth casting cavity as a comparatively smooth surface will be obtained even when the refractory particles are of a size sufficient to pass through screens having 149 meshes to 235 meshes per square inch. When extremely fine particles are utilized, it is therefore desirable to have coarser particles mixed therewith in amounts ranging up to 90%.

As a binder for the refractory particles which is effective in binding them to the frozen mercury pattern and together over a temperature range of from \(5^\circ\) to \(595^\circ\) centigrade, an organic material consisting of carbon and hydrogen but which contains some nitrogen atoms may be utilized, such as polymerized n-butylmethacrylate, high or low viscosity polymerized iso- butylmethacrylate, polymerized vinyl acetate, or ethyl cellulose that has been ethylated to an extent of 46.5% or more. For instance, an ethyl cellulose that has been ethylated to an extent of 46.5% to 48.5% may be utilized. An organic material consisting predominantly of carbon and hydrogen but which contains some nitrogen atoms may also be utilized, such as the copolymers of acrylonitrile and butadiene ranging in proportions from approximately 35% acrylonitrile and 65% butadiene to 60% acrylonitrile and 40% butadiene. A mixture of two or more of the binders may also be utilized.

The amount of the low temperature binder, or mixture of low temperature binders utilized, may vary from approximately 25% to 5% of the weight of the normally solid ingredients in the slurry which provide the films or layers for building up the shell mold after the liquid carrier vaporizes.

In preparing the slurry, a liquid is utilized which acts as a binder for the carrier, or mixture of binders, and which liquid may be a solvent or a partial solvent for the low temperature binder. For this purpose a liquid is utilized having a comparatively low boiling point so that it will volatilize at low temperatures in a comparatively short period of time. For instance, it must be in the liquid state at temperatures below \(-40^\circ\) centigrade, and should have a boiling point below \(20^\circ\) centigrade. A liquid which is a gas at normal room temperatures and has a boiling point below \(0^\circ\) centigrade is especially suitable because such liquids volatilize at normal atmospheric pressure at temperatures below \(-40^\circ\) centigrade in a comparatively short period of time. Liquefied monochlorodifluoromethane, liquefied methyl chloride, liquefied dimethyl ether, dichloromonofluoromethane, trichloromonofluoromethane, or a mixture of two or more of such liquids, may be employed. Liquefied monochlorodifluoromethane, liquefied methyl chloride and dichloromonofluoromethane, or a mixture of two or more of such liquids in any desired proportions, are solvents for all the low temperature binders mentioned, and polymerized n-butylmethacrylate, polymerized isobutylmethacrylate and polymerized vinyl acetate are also soluble in dimethyl ether. All of the liquids mentioned have a boiling point below \(0^\circ\) centigrade with the exception of dichloromonofluoromethane and trichloromonofluoromethane which boil at approximately normal room temperature and consequently the drying of a layer or film of the coating composition on a frozen mercury pattern will be slower when dichloromonofluoromethane or trichloromonofluoromethane is utilized than liquids which have a boiling point below \(0^\circ\) centigrade. When dichloromonofluoromethane and trichloromonofluoromethane are utilized, it is therefore desirable to mix one or both of them with a liquid having a lower boiling point, such as liquefied monochlorodifluoromethane. As the carrier, liquefied monochlorodifluoromethane has been found to be particularly suitable. Mixtures of certain of the liquids mentioned are also solvents for some of the binders. For instance, polymerized isobutylmethacrylate is soluble in a mixture consisting of 90% liquefied dichlorodifluoromethane and 10% of dichloromonofluoromethane, and ethyl cellulose and polymerized vinyl acetate are soluble in liquefied dichlorodifluoromethane when mixed with 30% or more of dichloromonofluoromethane.

A sufficient amount of the liquid carrier should
be present to provide a slurry of the desired viscosity which viscosity may of course be varied over a considerable range, such as from approximately 100 to 300 centipoises at -60° centigrade. For coating intricate patterns, the viscosity of the slurry must be low, such as from 100 to 150 centipoises at -60° centigrade, so that the slurry when applied will penetrate into small openings or indentations and will form a thin film or layer on blades or fins arranged in close proximity to each other, whereas for less intricate patterns, the viscosity of the slurry for preparing the coating may be higher, such as 150 to 300 centipoises at -60° centigrade.

In preparing a slurry for applying films or layers to build up the shell mold, a binder for the refractory material which becomes effective at raised temperatures may also be utilized in an amount sufficient to bind the refractory particles together after it becomes effective in binding such particles together, that is at temperatures ranging from approximately 315° to 505° centigrade, and which after becoming effective binds the refractory particles together up to the temperature at which molten metal is cast into the mold, such as at temperatures ranging up to approximately 1800° centigrade or higher, although it will be understood that after the raised temperature binder becomes effective in binding the refractory particles together, it will bind them together at low and normal as well as at high temperatures.

When a binder for the refractory material which becomes effective at raised temperatures is mixed with the slurry to form the shell mold, various binders may be utilized, such as primary, secondary or tertiary ammonium phosphates having a particle size ranging from 150 to 325 mesh or less, the alkali metal phosphates, or a mixture of an alkali metal and an ammonium phosphate, e.g., as the sodium metasilicates, the sodium fluorides, the sodium borates and the reaction product of the sodium fluoride and the refractory material.

The amount of the raised temperature binder which becomes effective at intermediate high temperatures in the layer or film of the applied coating must be sufficient to bind the refractory particles together after the shell mold has been heated to a temperature sufficient to cause the low temperature binder to volatilize or to decompose and volatile, or to become otherwise modified to provide vapors for producing a shell mold, and also during the casting of metal into the shell mold. Amounts ranging from approximately 1% to 5% of the total amount of solids in the applied layer or film which remains after the liquid vaporizes, depending upon the particular binder that is utilized, have proven satisfactory. When primary ammonium phosphate is utilized as the binder which becomes effective as a binder for the refractory particles at intermediate high temperatures, approximately 2% to 4% of the binder, based on the total amount of solids in the applied film or layer remaining after the liquid vaporizes, has been found to be especially suitable.

The following are specific examples of a composition for application to a frozen mercury pattern, such as that shown in Figs. 1 to 3 to form a shell mold:

**Example I**

<table>
<thead>
<tr>
<th>Grams</th>
<th>Liquefied monochlorodifluoromethane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30.500</td>
</tr>
<tr>
<td></td>
<td>Polymerized vinyl acetate having a viscosity of 700 to 900 centipoises at 50° centigrade with molar solution in benzene</td>
</tr>
<tr>
<td></td>
<td>Phenol - formaldehyde condensation product condensed to intermediate soluble stage</td>
</tr>
<tr>
<td></td>
<td>Primary ammonium phosphate, 325 mesh</td>
</tr>
<tr>
<td></td>
<td>Zirconium silicate, 325 mesh</td>
</tr>
</tbody>
</table>

**Example II**

<table>
<thead>
<tr>
<th>Grams</th>
<th>Liquefied monochlorodifluoromethane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10,500</td>
</tr>
<tr>
<td></td>
<td>Ethyl cellulose that has been ethylated to a mixture of two or more of such compounds. An alkali metal borate or an alkali metal tetraborate, such as a borate or tetraborate of sodium, potassium, or lithium, or a mixture of compounds which react on heating to form an alkali metal borate or an alkali metal tetraborate and an alkali metal fluoride may be utilized. For instance, a mixture of sodium fluoride and lithium fluoride and a boron compound, such as boric acid or boric oxide, has been found to be satisfactory. When a shell mold containing sodium fluoride and boric acid or boric oxide is heated to approximately a red heat, the sodium fluoride and boric compound react to form molten borax which envelopes the grains of the refractory material to provide a binder therefor. When utilizing an alkali metal fluoride and a boron compound, such as boric acid or boric oxide, it is desirable, however, to mix the compounds together in such proportions that some of the alkali metal fluoride will be present after the reaction takes place. For instance, approximately three parts by weight of the sodium fluoride may be utilized to one part by weight of the boric acid in which case the raised temperature binder for the refractory material which becomes effective at intermediate high temperatures consists of a mixture of a sodium borate and the reaction product of the sodium fluoride and the refractory material.</td>
</tr>
<tr>
<td></td>
<td>Phenol - formaldehyde condensation product condensed to intermediate soluble stage</td>
</tr>
<tr>
<td></td>
<td>Boric acid</td>
</tr>
<tr>
<td></td>
<td>Sodium fluoride</td>
</tr>
<tr>
<td></td>
<td>Zirconium silicate, 325 mesh</td>
</tr>
</tbody>
</table>

In preparing a slurry from either of the compositions disclosed in Example I or Example II, the solid ingredients of the composition including the polymerized vinyl acetate, the polymeric vinyl acetate and ethyl cellulose, the phenol-formaldehyde condensation product, the ammonium phosphate particles, or the mixture of sodium fluoride and boric acid, and the zirconium silicate, are precooled to a temperature below -40° centigrade and are then thoroughly mixed with the liquefied monochlorodifluoromethane and the slurry thus obtained is maintained below -40° centigrade and is applied to the frozen mercury pattern at temperatures be-
low -40° centigrade by any desirable method, such as by dipping, pouring, brushing, or spraying. For instance, in building up the shell-like structure 8 as shown in Fig. 6, the composition may be applied to the frozen mercury pattern shown in Figs. 1 and 2, including the opening 4 and the interior portion of the frozen mercury pattern, by dipping the pattern in the slurry while the slurry is maintained below the freezing point of the frozen mercury. The pattern to provide a film or layer which must be dried, at least partially dried, at temperatures below the freezing point of the mercury, which process may be repeated a sufficient number of times to build up the shell-like shaped structure 8 shown in Figs. 3 to 5. It is essential that the drying or partial drying not take place below the freezing point of the liquid carrier utilized in forming the slurry, otherwise, a smooth coating will not be obtained.

The phenol-formaldehyde condensation product is utilized to improve the adherence of the coating to the frozen mercury pattern and the cohesiveness of adjacent films or layers to each other. Its presence in the coating composition, however, is not essential, and, if desired, it may be omitted.

According to the present process, the coated mercury pattern is suspended in a flask 9 and a refractory material 10 formed of small particles is interposed in any desired manner, such as by pouring or blowing, between the coated pattern and the flask while the pattern and flask are maintained below the freezing point of the mercury and serves to absorb any residual liquid carrier which has not previously been volatilized and as a supporting means for the coated pattern during the liquefaction of the mercury and for the shell mold during the casting of molten material therein. Any suitable refractory material may be utilized for this purpose. A refractory material composed of particles having smooth round surfaces which are easily displaced relative to adjacent particles, such as sand, however, is not entirely satisfactory, although it may be used. A more desirable refractory material is an organic aggregate having a low specific gravity and irregular surfaces in which each particle resists displacement relative to adjacent particles, such as cinders, ground titanium metal, aluminum oxide, ground fused quartz, or a treated micaceous material that expands under the influence of heat, such as vermiculite. For instance, vermiculite particles may be ground and screened to provide substantial uniformity as to size and treated with an aqueous solution of phosphoric acid ranging in strength from 10% to 55%. The treated vermiculite may then be spread on a screen and heated in a furnace to a temperature of approximately 1000° centigrade for fifteen to thirty minutes, or vermiculite may be mixed with a slurry, such as disclosed in Examples I and II, and the slurry passed through a screen of sufficiently fine mesh to retain all the coated vermiculite particles. The vermiculite particles may then be spread on the screen and heated in a furnace to a temperature of approximately 1000° centigrade for fifteen to thirty minutes and the fired particle may then be ground and screened to provide a suitable material to be used in the present process.

The refractory particles utilized to support the coated pattern may range in size from those passing through a 4 mesh screen to those retained on a 32 mesh screen. When the coated pattern is of small size and is complicated in shape, small size particles, such as particles passing through an 8 mesh screen and retained on a 20 mesh screen may be utilized, whereas larger sized particles, such as those passing through a 4 mesh screen and retained on a 16 mesh screen, may be utilized when the shell mold is in shape or is of a larger size.

When supporting coated patterns having a comparatively thin coating, it is usually desirable to chill the refractory particles utilized as the supporting material before they are introduced into the flask to prevent premature liquefaction of the frozen mercury pattern. When the frozen mercury pattern is provided with a comparatively thick coating, the coated pattern may usually be embedded in the refractory particles before any liquefaction of the frozen mercury takes place.

As illustrated in Figs. 4 and 5 of the drawings, it will be noted that the refractory supporting particles may not only be interposed between the flask 9 and the coated pattern but during the introduction of the refractory particles, they may be introduced through the opening 4 into the hollow space 3 in the coated pattern and serve to absorb any of the liquid carrier that has not been volatilized during the drying process.

After the refractory material is introduced in place, the flask containing the loose refractory particles and the coated pattern is subjected to such temperature that the frozen mercury liquifies. The flask is then inverted to remove the liquefied mercury from the coating to form the shell mold, and to prevent loose supporting particles from being displaced from the flask during this operation, a cover 11 is placed over the flask. The cover 11 may be formed of any suitable material, such as fabric, plastic, or rubber, and when assembled in place has a reinforced portion 12 adjacent that portion of the coating 13 formed around sprue 9 and a downwardly extending flange 14 provided with a reinforcement 15 engaging the upper edge of the flask. The cover 11 may then be removed.

When a binder is present in the shell mold which becomes effective at raised temperatures, the flask containing the loose refractory particles and the shell mold is then baked or fired in a furnace to a sufficient temperature to cause the raised temperature binder in the shell mold to become effective as a binder for the refractory particles in the shell mold and to cause a modification of the low temperature binder to provide a vapor for producing a porous shell mold, such as at temperatures ranging from approximately 540° to 1250° centigrade.

When the mold structure is subjected to the temperatures specified, the flask 9 must of course be formed of a material that is capable of resisting such temperatures, such as a metal having a high fusion point or a The refractory particles or materials may also be mixed with water glass of any desired concentration, such as aqueous solutions of sodium or potassium silicate having a specific gravity ranging from approximately 30° to 42° Baumé. The refractory particles coated with the water glass may then be spread on a screen and heated to a temperature of from approximately 550° to 1100° centigrade to cause the water glass to set and adhere to the refractory particles.
utilized as the supporting material for the shell mold, they are slightly adherent to each other when the mold structure is heated to temperatures sufficient to cause the raised temperature binder to become effective but do not have sufficient rigidity to prevent the shell mold from yielding during the casting of molten metal into the shell mold or when molten metal which is cast into the shell mold contracts about portions of the shell mold during cooling.

When metal having a high fusion temperature is to be cast into a shell mold, or in preparing castings having thin wall sections, it is desirable to first heat the shell mold before the molten metal is cast therein. In casting molten metal having a low fusion point into a shell mold, it is also desirable to cast the metal into the shell mold while the shell mold is hot to prevent solidification of the metal before it completely fills the mold. According to the present invention, if the shell mold contains a raised temperature binder, the shell mold is first embedded in the supporting refractory particles and the mold structure thus provided is heated to a temperature sufficient to cause the raised temperature binder in the shell mold to become effective as a binder for the refractory particles and molten metal is then cast into the shell mold while the mold structure is still hot.

In retrieving the casting, the loose refractory particles may be poured from the flask and reutilized in subsequent operations. If the refractory particles have been coated with a silicate and have become slightly bound together during the heating of the mold structure to a temperature sufficient to cause the raised temperature binder to become effective as a binder for the refractory particles in the shell mold, the bound particles may be broken apart before reuse or after being reused several times, they may be again coated with water glass spread on a screen and heated to a temperature ranging from 535° to 1100° centigrade.

After the loose or slightly bound refractory particles are removed from the flask, the shell mold containing the casting may also be removed from the flask and a large portion of the shell mold may be easily removed from the casting. The remainder of the shell mold may then be removed from the casting by blasting, such as sand blasting.

When a metal has a fusion point below the temperature at which the low temperature binder loses its binding properties, or when a plastic material, such as a resin or an ester gum, is to be cast into the shell mold, it is not necessary to heat the flask containing the refractory material and the shell mold to cause the raised temperature binder to become effective in binding the refractory particles together and in such cases the raised temperature binder may be omitted. For instance, the composition for forming one or more layers for building up the coating may be formed from the following composition:

**Example III**

<table>
<thead>
<tr>
<th>Component</th>
<th>Grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquefied monochlorodifluoromethane</td>
<td>5000.0</td>
</tr>
<tr>
<td>Polymerized vinyl acetate having a viscosity of 700 to 900 centipoises at 20° centigrade with a molar solution in benzene</td>
<td>81.0</td>
</tr>
<tr>
<td>Phenol-formaldehyde condensed to its intermediate soluble stage</td>
<td>40.5</td>
</tr>
<tr>
<td>Zirconium silicate, 325 mesh</td>
<td>7978.5</td>
</tr>
</tbody>
</table>

The coating composition in Example III may be prepared by precooling the solid ingredients, namely, the polymerized vinyl acetate, the phenol-formaldehyde condensation product, and the zirconium silicate, and mixing them with the liquefied monochlorodifluoromethane to provide a slurry. If the pattern is complicated in shape, an additional amount of the liquefied monochlorodifluoromethane may be added to provide a slurry of the desired viscosity.

The composition may be applied to the frozen mercury pattern by the method previously described and each film or layer is at least partially dried at a temperature below the freezing point of the mercury and below the boiling point of the liquid carrier. After the final film or layer is dried, the coated pattern may be suspended in flask 3 and embedded in the loose refractory particles 10 interposed between the flask 3 and the coated pattern while the coated pattern is maintained at temperatures below 40° centigrade and the mold structure thus formed is subjected to such temperature that the frozen mercury is liquefied. The liquefied mercury is then removed from the coating to provide a shell mold into which the molten metal may be cast. Because no high temperature binder is present in the shell mold, the refractory material may be easily removed from the casting.

Instead of casting metal into the shell mold while the shell mold is at normal or high temperature, the shell mold may be precooled and the molten metal cast into the shell mold while it is maintained at temperatures below 0° centigrade, such as at temperatures ranging from -40° to -100° centigrade. In preparing the shell mold for casting metal at low temperatures, a coating composition as disclosed in Example III may be applied to a frozen mercury pattern in the manner previously specified and after the coating is dried, the frozen mercury pattern may be suspended in flask 8 and supported by refractory material 10 as previously described. A liquid having a higher freezing point than water, such as water or a mixture of water and alcohol, may then be poured into the flask containing the refractory particles and the coated mercury pattern. The flask, together with the refractory material and the frozen mercury pattern, is then placed in a cold cabinet which is maintained at sufficient temperature to freeze the water or other liquid utilized but at such temperature that the mercury will liquefy in which case the liquefaction of the mercury aids in freezing the water.

The flask, together with the frozen refractory particles and the shell mold, may then be inverted to remove the liquefied mercury, the refractory particles bound together by the frozen material being held in place by the cover 11 during this process.

The flask containing refractory particles bound together by the ice and the shell mold is then placed in a cold cabinet and subjected to a temperature ranging from -40° to -100° centigrade or lower, for about one-half hour. It is then removed from the cold cabinet and metal having a high fusion temperature may be cast into the mold, such as stainless steel or an alloy commercially known as Colomony 6 which consists essentially of 65% to 75% nickel, 13% to 20% chromium, and from 2.75% to 4.75% boron and which has a melting point of approximately 1850° centigrade.

During the casting of metal into such molds, the water of course liquefies and the low-
perature binder is modified by a change in its physical or chemical state to provide a vapor and consequently the refractory material falls from the casting. In the event that any of the refractory particles cling to the casting, they may be easily removed by any suitable liquid, such as water.

Although the present invention is not limited thereto, it is particularly adapted to be utilized in preparing castings in which the molten metal contracts about the pattern during cooling because in such cases, it is necessary to provide a shell mold, or at least a portion thereof, that is thin enough to yield to prevent cracks from forming in the casting.

Because a frozen mercury pattern has a low thermal coefficient of expansion that approximates zero at its melting point, it may be liquefied and removed from a dried coating containing a refractory material and a binder that is applied thereto to provide a shell mold in which the thickness of the shell mold is extremely thin. It is therefore quite possible that the casting mold of sufficient thickness to resist the impact of molten metal cast into the cavity of the shell mold.

In the mold structure shown in Fig. 4, the loose refractory particles interposed between the shell mold 8 and the flask 9 and the refractory particles in the hollow interior portion 3 of the shell mold, serve to support the shell mold during the casting of hot metal therein and consequently, a comparatively thin shell mold in conjunction with the loose refractory particles will serve to reduce the impact of the molten metal cast into the shell mold. For instance, when the average thickness of the frozen mercury pattern of the object to be cast as shown in Figs. 1 and 2 varies from approximately 1/10 to 1/10 of an inch, a coating 4 having an average thickness ranging from approximately 1/10 to 1/10 of an inch is sufficient when utilized in conjunction with the loose refractory particles to resist the impact of molten metal which is cast into the shell mold cavity and such a shell mold is thin enough to yield when the casting contracts about portions 8a of the shell mold during cooling, to thereby prevent cracks from forming in the casting. In the structure shown in Fig. 4, it will be noted that during the casting of the molten metal in the shell mold and during the contraction of the molten metal about portions of the shell mold during cooling, the supporting refractory particles include at least one backing layer contacting the exterior side of the thin shell mold and that adjacent portions of the supporting material are movable relatively to adjacent surfaces of the wall portions of the shell mold to permit the wall portions of the shell mold to yield while substantially preventing displacement of the shell wall portions in a lateral outward direction.

It will of course be understood that as the thickness of the frozen mercury pattern of the object to be cast is increased, the thickness of the coating layer which is applied to the frozen mercury pattern must also be increased to provide upon the liquefaction and removal of the mercury a shell mold of sufficient thickness to resist, in conjunction with the loose refractory particles, the impact of molten metal cast into the shell mold. In such cases, the amount of molten metal cast into the shell mold will be larger than when a small casting cavity is provided and consequently will have a greater impact upon the shell mold and the casting that is formed will exert a greater force upon those portions of the shell mold about which the molten metal contracts during cooling than when a thin coating is formed. When the volume of the frozen mercury pattern for the object, it is not necessary, however, to increase the thickness of the applied coating in the same ratio because in such cases only a slight increase in the thickness of the coating layer will provide upon the liquefaction and removal of the mercury a shell mold which, together with the loose refractory particles, has sufficient strength to resist the impact of the molten metal which is cast into the shell mold and even when the shell mold is of considerable size, the average thickness need not be greater than 1/10 to 1/10 of an inch, and for comparatively large molds, the average thickness of the shell mold need not be greater than 1/10 to 1/10 of an inch, and since in such cases, a large amount of the molten metal is required to fill the cavity of the shell mold, the contraction of metal about portions of the shell mold during cooling will cause the comparatively thin shell mold to yield to prevent cracks from forming in the casting.

The claims herein are directed to features of a process for forming a thin hollow shell mold over a frozen mercury pattern including the steps of suspending the pattern together with the shell mold in a flask, interposing loose refractory particles between the shell mold and the flask, and thereafter liquefying the frozen mercury of the pattern and removing it from the flask after first solidifying the shell mold. The features of the shell mold structure disclosed herein constitute the subject matter of application Ser. No. 381,723, filed September 22, 1953, as a continuation in part of the present application. Other features of invention disclosed herein constitute the subject matter of copending applications Ser. Nos. 257,328, filed November 20, 1951; Ser. Nos. 304,301, 304,302 and 304,309, filed August 14, 1952, by applicant jointly with Z. Kasenas.

What is claimed is:

1. The method of precision casting a metal object which comprises the initial procedure of producing a hollow mold structure in the form of a thin shell layer over the exposed surfaces of a frozen mercury pattern of the cast object which initial procedure comprises preparing a liquid slurry-like investment composition which will adhere to said frozen mercury pattern surfaces when applied thereto as a coating stratum at very low temperatures below the freezing temperature of mercury which investment composition comprises refractory particle material of fine particle size constituting a predominant amount of the normally solid composition ingredients applied to form the shell layer, a raised temperature binder that forms about 0.1 to 5% by weight of said solid composition ingredients and becomes effective in binding the refractory particles together at temperatures ranging from approximately 315° to 595° centigrade and which is present in an amount sufficient to bind the refractory particles together after it becomes effective in binding such particles together, a low temperature binder that is effective in binding and which is present in an amount sufficient to bind the refractory material and the raised temperature binder to the frozen mercury pattern and the refractory material and the raised temperature binder together at temperatures ranging from said very low temperatures up to the temperature at which the raised temperature
binder becomes effective in binding the refractory particles together and which low temperature binder becomes modified to provide vapors for producing a porous shell mold when the mold structure is heated to temperatures above the temperature at which the raised temperature binder becomes effective in binding the refractory particles together, and a liquid carrier for said refractory particles and said binders that is in the liquid state at said very low temperature and has a boiling point below 0° centigrade and which is present in an amount to provide a slurry of sufficiently low viscosity to enable the composition to be applied to the frozen mercury pattern in the form of layers or films, thereafter applying said composition to said pattern at said very low temperatures as coating strata until there is formed a shell layer which adheres to said pattern and has a small thickness of at most about ¼ inch and which after making the raised temperature binder effective has a wall thickness which permits the thin shell layer walls to yield when molten metal cast into the shell layer mold cavity contracts around portions of the shell layer, drying the applied layers or films at said very low temperatures and below the boiling point of the liquid carrier, and the further procedure which comprises suspending the mercury pattern with the adhering shell layer in a flask, interposing between the flask and the exterior of the shell layer adhering to the pattern additional loose refractory particles for absorbing any liquid carrier of the shell layer that has not vaporized and for supporting the thin shell layer adhering to said pattern within the flask, while maintaining said pattern at said very low temperatures, thereafter liquefying the mercury of the pattern and removing the liquefied mercury from the mold cavity of said shell layer so supported in said flask, thereafter heating the flask with the shell layer so supported therein to a temperature sufficient to cause the raised temperature binder in the shell layer to become effective in binding the refractory particles of the shell layer and to modify the low temperature binder and to provide vapors which leave the shell layer and render it porous, and thereafter casting hot molten metal into the mold cavity of the shell mold layer while so supported in said flask.

2. The method of precision casting as claimed in claim 1, wherein the additional loose refractory particles interposed between the flask and the shell mold layer are of a minus 4 mesh, to plus 32 mesh particle size and are irregularly shaped.

3. The method of precision casting as claimed in claim 1, wherein said frozen mercury pattern has spaced pattern wall portions united by an intermediate pattern wall portion, and wherein said composition is applied to said pattern including the surfaces of said pattern wall por-

4. The method of precision casting as claimed in claim 3, wherein the hot metal is cast into the mold cavity while the flask and the shell layer supported therein are at an elevated temperature.

5. The method of precision casting as claimed in claim 3, wherein the hot metal is cast into the mold cavity while the flask and the shell layer supported therein are at temperatures below 0° C.

6. The method of precision casting as claimed in claim 1, wherein said frozen mercury pattern has a pattern opening extending through a body portion of said pattern and wherein said composition is applied to said pattern including the surfaces surrounding said pattern opening to form a shell layer having a core-like shell layer portion projecting into the mold cavity until there is formed a shell layer having a wall thickness which after making the raised temperature binder effective has at least in the region of the core-like shell layer portion sufficiently thin to yield when molten metal cast into the mold cavity contracts around the core-like portion while cooling.

7. The method of precision casting as claimed in claim 6, wherein the hot metal is cast into the mold cavity while the flask and the shell layer supported therein are at an elevated temperature.

8. The method of precision casting as claimed in claim 6, wherein the hot metal is cast into the mold cavity while the flask and the shell layer supported therein are at temperatures below 0° C.

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