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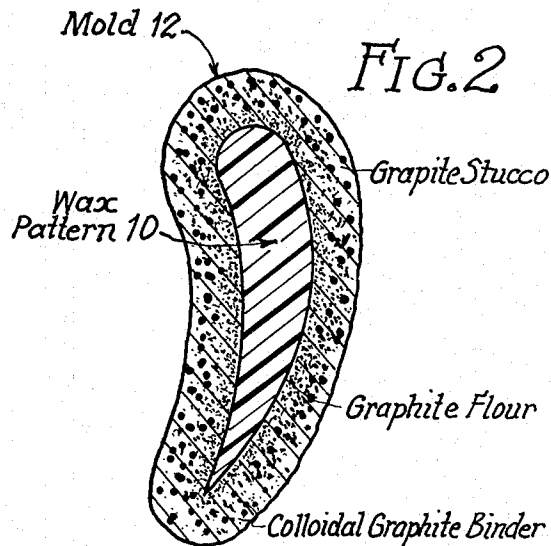
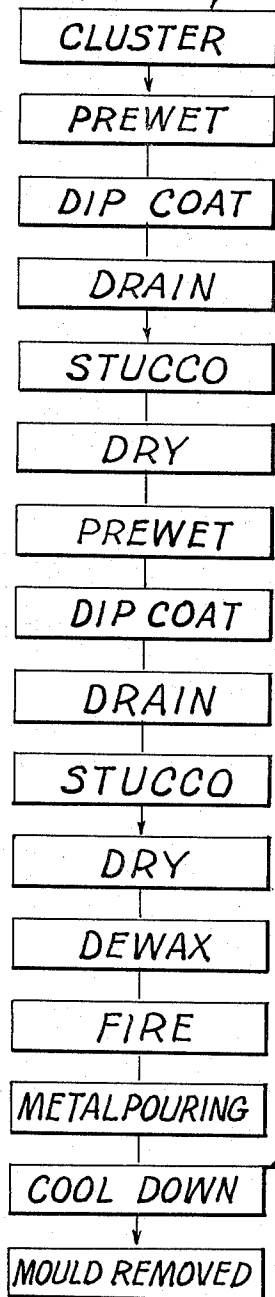
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3,241,200

PRECISION MOLD AND METHOD OF FABRICATION

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PATTERN PATTERN FIG. 1



"N" Times

Vacuum

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3,241,200

PRECISION MOLD AND METHOD OF FABRICATION

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This invention relates to the art of precision casting and to materials employed in the practice of same and it relates more particularly to a casting process and to compositions and methods for the preparation of the molds in the practice of same.

It is an object of this invention to produce and to provide a method for producing new and improved molds for use in the precision casting of various materials and it is a related object to provide a new and improved molding process employing the same and to provide compositions for use in the preparation of same.

More specifically, it is an object of this invention to produce a mold which is of sufficiently high strength and stability to enable materials to be poured directly therein for molding; in which refractory or other high melting point metals can be molded; in which metals can be formed in a manner to minimize oxidation thereby to enable use of the process and materials in the molding of metals that have heretofore been difficult to shape, and it is a related object to provide a new and improved molding process which can be easily carried out for the precision casting of materials which have heretofore not been easily adaptable to molding and in which the molded products can be easily and efficiently separated from the mold cleanly to release the molded product.

These and other objects and advantages of this invention will hereinafter appear and for purposes of illustration, but not of limitation, an embodiment of the invention is shown in the accompanying drawings in which:

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

FIG. 2 is a schematic sectional view through a pattern having a mold formed therein in accordance with the practice of this invention.

In accordance with the practice of this invention, at least the inner portions and preferably the entire cross-section of a mold is of graphitic material formed on the surface of a heat or otherwise disposable pattern by series of intergrated layers of dip coats and stucco coats but in which the essential solids of the dip coat composition and the stucco, including the binder, are all graphitic, as will hereinafter be described. A mold of such graphite material is capable of use at considerably higher temperatures than ceramic materials and many other new and novel characteristics are made available which enable use of the shell for the molding of high alloy and refractory metals.

The new and novel mold will be described with reference to new and improved compositions employed and the methods of manufacture in a representative process illustrating the practice of this phase of the invention.

In the following description, the terms "pattern" and "cluster" will be used interchangeably to refer to the wax or plastic pattern 10 or a cluster formed of a multiplicity of such individual patterns. It will be understood that changes may be made in the details of formulation, materials and methods employed without departing from the spirit of the invention.

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EXAMPLE 1

Preparation of wax pattern and cluster

The pattern 10 is formed of conventional materials disposable by heat or chemicals, as in the well known investment casting processes. In the illustrated modification, the pattern is molded under pressure in suitable metal molds by injection of molten wax to fill the mold and set the pattern. Instead, the pattern can be formed of a thermoplastic, synthetic resinous material or combinations of such plastics and wax.

If the mold is to be formed about more than one pattern, the plurality of patterns are connected by runners for communication with a pouring spout to form a completed cluster, as described in the Operhall et al. Patent No. 2,961,751. Where, as in the instant process, the cluster is to be repeatedly dipped into a slurry, identified as a dip coat, it is desirable to provide a hanger rod for carrying the cluster and for suspending the cluster for drying and the like.

EXAMPLE 2

Dip coat composition

2.77 percent by weight solids of colloidal graphite (22% solids in aqueous medium—"Aquadag" of National Carbon Company)
37.8 percent by weight solids of graphite flour (less than 200 mesh)
0.174 percent by weight emulsifying agent (gum tragacanth)
0.003 percent by weight anionic wetting agent (sodium heptadecyl sulphate)
Remainder water

As the colloidal graphite, it is preferred to make use of colloidal particles of graphite of less than 1 micron. For the purpose of reducing cost, use can be made of a combination of such colloidal graphite mixed with up to 50 percent by weight and preferably up to only 30 percent by weight of semi-colloidal graphite having a particle size of between 1–20 microns.

The amount of colloidal graphite in the dip coat composition may vary but it is desirable to make use of an amount greater than 0.5 percent by weight but less than 5 percent by weight and preferably an amount within the range of 1 to 3.0 percent by weight.

In the dip coat compositions represented by the above formulation, the emulsifying agents and the anionic wetting agents are preferred but not essential. Instead of gum tragacanth, use can be made of other hydrophilic colloids such as the gums, gelatins, alginates and the like, wherein, when used, such emulsifying agents are employed in an amount within the range of 0.01 to 0.5 percent by weight. Instead of the sodium heptadecyl sulphate wetting agent, other anionic surface active agents may be employed such as the allyl sulphates and the allyl aryl sulfonates and their salts. When employed, the amount of such surface active agent may range from 0.01 to 0.5 percent by weight of the composition.

The dip coat composition will have a pH within the range of 8.8 to 9.4 and a viscosity measured by the cup of Patent No. 3,011,986 of between 25–35 seconds.

The solids content, insofar as the colloidal or semi-colloidal graphite and graphite flour is concerned, can be varied quite widely, it being necessary only to formulate for a viscosity that can be handled to coat the pattern and to make use of colloidal or semi-colloidal graphite in an amount sufficient to achieve the desired bonding ac-

tion. For this purpose, it is deemed sufficient if the latter is present in an amount to make up more than 1.5 percent by weight of the graphite solids of the dip coat composition and it is usually undesirable and uneconomical to make use of an amount of colloidal or semi-colloidal graphite greater than 10 percent by weight of the graphite in the dip coat composition. It will be understood, however, that the essentially 100% graphite making up the solids in the dip coat composition can be achieved by the use of colloidal or colloidal and semi-colloidal graphite alone.

Application of dip coat composition

The wax pattern or cluster is first inspected to remove dirt, flakes and other objects which may have adhered to the surfaces of the wax patterns and which, if allowed to remain, would impair the preparation of a good mold and lead to an imperfect casting. The cleaned cluster is immersed into the dip coat composition, while being stirred, to cover all of the surfaces of the cluster with the exception of the lip of the pouring spout. To promote the elimination of air pockets, it is desirable to rotate the cluster while immersing in the dip coat composition. Instead of immersing the pattern in the stirred slurry of the dip coat composition for coverage of the surfaces of the pattern, the dip coat composition can be applied to achieve the desired coverage by spraying the dip coat composition onto the surfaces of the pattern. By this latter spraying technique the coating weight of the dip coat composition can be increased or decreased, as desired, by comparison with the amount of coating retained on the surfaces by immersion.

When fully coated, the pattern or cluster is suspended to drain excess dip coat composition. During drainage, the cluster can be inspected to detect air pockets which can be eliminated by addressing a stream of air onto the uncoated portions and thereafter allowing the slurry of the dip coat composition to flow onto the uncovered areas. While the cluster is being drained, it should be held in different planes designed to achieve uniform coating on all surfaces. In general, drainage should be completed within a few minutes but, in any event, in less time than would allow the dip coat composition to dry whereby the surface would not retain stucco in the desired uniform arrangement.

EXAMPLE 3

Stuccoing

After the cluster has been allowed to drain for a short time and while the surface is still wet with the dip coat composition, the surface is stuccoed with particles of graphite having the following particle size distribution.

Tyler screen size:	Percent retained on screen
65	62
100	29
150	7
200	1
Pan	1

The graphite will hereinafter be referred to as having a particle size of more than 150 mesh but less than 35 mesh. The particles of graphite are caused to flow over the surface of the pattern until the wet surface is substantially completely covered.

Application of stucco coat

After the uniformity of coating has been achieved with the dip coat composition, the stucco is sprinkled onto the wet surface while constantly changing the position of the cluster substantially uniformly to cover the dip coating with a layer of stucco, while at the same time minimizing flow of the dip coat composition whereby non-uniformities might otherwise develop. In practice, the graphite particles are rained down from above through a screening member which is constantly fed from a vibra-

tory conveyor. The particles of graphite adhere to the wet coating and become partially embedded therein to become integrated with the coating formed on the wax patterns.

If the dip coat composition is adjusted to enable gellation to take place within a very short period of time, the stuccoed cluster need not be set aside for drying. However, it is preferred to slow the drying of the dip coat so that sufficient leeway is available for the desired drainage and stucco application. Thus it is desirable to provide for an air dry for a time ranging from 10-25 minutes. It will be understood that the drying time may be extended indefinitely beyond the times described without harm to the structure. If desired, drying of the combined coatings can be accelerated in a humidity controlled air circulating chamber heated to a temperature up to about 100° F.

The particle size of the graphite stucco is not critical since the particle size of the graphite can be varied over a fairly wide range. However, for best practice of this invention, it is preferred to make use of graphite having a particle size greater than 150 mesh and less than 20 mesh.

The operation is repeated, that is the pattern is again dipped into the dip coat composition and covered with fine particles of graphite to build up a second composite layer. In the preferred practice of this invention, it is desired, though not essential, to precede the immersion of the coated pattern in the dip coat composition with a pre-wetting step in which the prewetting composition employs substantially the same formulation as the dip coat composition with the exception that a lower viscosity is employed occasioned by the formulation to include additional amounts of water sufficient to reduce the total solids to about 25-75% of the solids in the dip coat composition. Thus the coated pattern is first submerged in the prewet composition more completely to penetrate and wet out the coated surface followed almost immediately by submersion in the dip coat composition after which the steps of drainage, stuccoing with the fine particles of graphite, and drying are carried out. Thus the layers become better integrated one with the other to produce a strong and composite structure.

The steps of prewetting, if used, dip coating, stuccoing with the dry particles of graphite and drying can be repeated several times until a mold 12 of the desired thickness and strength has been built up about the disposable pattern or cluster.

While a mold of higher strength will be secured if the graphite particles of the type having a mesh size within the range of more than 150 but less than 20 are used throughout to build up the mold, it is preferred to make use of particles of graphite of larger dimension for use as the stucco after the second coat and preferably after the fifth coat. For such outer layers or coatings, graphite having the following particle size distribution may be employed.

Tyler screen size:	Percent retained on screen
8	1
10	14
20	65
35	18
65	1
Pan	1

The foregoing will hereinafter be referred to as having a particle size greater than 35 mesh but less than 8 mesh.

A mold 12 having a wall thickness of from ¼ to ½ inch is usually sufficient for the coating of products of normal weight or dimension by molten metal casting, although molds of greater wall thickness can be formed where greater strengths are desired for use in the molding of larger castings. The normal wall thickness of mold can be achieved with the compositions described

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with from 5-10 cycles of dip coating, stuccoing, and drying.

EXAMPLE 4

Dewaxing

After the composite mold has been produced, the disposable pattern is removed to leave a mold cavity in which the material to be molded may be cast. Pattern removal, hereinafter referred to as dewaxing, can be achieved in a number of ways:

(a) Use can be made of flash dewaxing wherein the composite is heated to an elevated temperature far above the melting point temperature of the wax or plastic. In a preferred process of flash dewaxing, the composite is heated to a temperature above 800° F. and preferably to a temperature within the range of 800-2200° F. for a time sufficient to eliminate the wax and to fire the mold. When the mold is exposed to a temperature in excess of 800° F. during dewaxing or firing, it is desirable to enclose the mold within a reducing or non-oxidizing atmosphere, otherwise the graphite binder will be burned out.

(b) Dewaxing can be carried out by a process referred to as "hot sand dewaxing" wherein sand heated to a temperature of 400-800° F. is arranged to surround the composite for intimate contact with the outer surfaces thereof whereby rapid heat transfer is achieved into the interior to melt out the wax. The hot sand can be poured about the mold or the mold can be buried in the hot sand. Instead of sand, use can be made of a metal or alloy system of low melting point such as the cerro alloys, low eutectic alloys, and the like.

(c) Dewaxing can be carried out with steam when the wax patterns are formed of a material having a melting point range below 200° F. For such purpose, the composite can be housed within a steam chamber or autoclave or else steam at relatively high pressure can be addressed onto the composite while it is suspended with the spout extending downwardly for drainage of the molten wax.

(d) Dewaxing can be carried out in an oven heated to a temperature above the melting point temperature of the wax but below the oxidizing temperature of the graphite, or preferably at a temperature within the range of 250-800° F. in a process referred to as "low temperature dewaxing," without the need to maintain a reducing atmosphere.

The mold is thereafter fired by heating to a temperature above 800° F. and preferably to a temperature within the range of 800-2200° F. Firing can be achieved by exposure of the mold to firing temperature for 15 or more minutes but it is preferred to fire the mold at a temperature within the range of 800-2200° F. for a time within the range of 15-120 minutes. Firing can be carried out concurrently with dewaxing when use is made of a high temperature dewaxing method as described in (a) above. Since graphite will be consumed when heated to a temperature above 800° F. in an oxidizing atmosphere, high temperature dewaxing and firing are carried out in an inert atmosphere and preferably in a reducing atmosphere. For this purpose, use can be made of hydrogen or an atmosphere composed of nitrogen or carbon monoxide.

Because of the thinness of the walls of the mold and the high heat conductivity of the graphite, heat penetrates rapidly through the mold to cause the wax portion of the pattern immediately adjacent the inner surfaces of the mold to be reduced to a molten state even before the remainder of the pattern has been heated to elevated temperature. Thus the liquefied portion leaves sufficient room to permit expansion of the remainder of the wax pattern when the cross-section of the pattern is heated to elevated temperature thereby to eliminate strain on the shell which might otherwise lead to breakage.

The fired mold is cooled from firing temperature to a safe temperature below 800° F. before exposure to atmospheric conditions for continued cooling or for further processing.

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The fired mold can be used in the "as fired" state for the conventional casting of molten metal.

In the casting of molten materials such as high alloy metals and the like, it is preferred to densify the interior wall portions of the graphite mold defining the mold space to minimize flow of molten material into or through the mold. For this purpose, the mold can be impregnated with a graphite formulated in an impregnating composition represented by the following:

EXAMPLE 5

Impregnating composition A

0.5 lbs. colloidal graphite
11.5 lbs. acetone

Impregnating composition B

2 lbs. colloidal graphite (22% solids in aqueous medium—less than 1 micron)
10 lbs. distilled water
25 cc. anionic wetting agent

For purposes of impregnation, only colloidal graphite of less than 1 micron should be used. Impregnation can be achieved merely by dipping the fired mold in the impregnating composition whereupon the composition soaks rapidly into the walls of the mold. Impregnation is followed by drying. As many as from 1 to 10 or more impregnations can be effected whereby the pores of the fired mold are increasingly filled with graphite by each impregnation. After one or a series of such impregnations, with intermittent drying, the mold should again be fired at a temperature within the range of 800-2200° F. in a reducing or inert atmosphere for about 15-120 minutes. The resultant product, upon cooling, will be found to be of such hardness and density as to give a metallic ring.

To the present description has been made of the process and compositions wherein a mold formed substantially entirely of graphite is produced. The description will hereafter be made to the use of the new and novel graphite mold of this invention in the fabrication of shaped products by such means as metal casting and vacuum casting of molten metals.

Molten metal can be poured directly into the mold cavity of the graphite mold for the fabrication of molded products of metals of the type generally limited to the field of precision casting. The fired graphite mold possesses sufficient strength and has sufficient mass integrity to enable the molten metal to be poured into the mold without investment thereby to achieve the many advantages by comparison with investment casting such as less weight, less material, more rapid heat-up, more rapid cooling, better control of tear strength, fuller inspection, lower scrap loss, and the like. The mold can be clamped to the furnace without additional reinforcement or support when the molten metal is poured therein. However, because of the nature of the mold formed of graphite, various modifications are required from conventional molding techniques.

While preheating is not essential, it is desirable to preheat the mold prior to metal pouring. When preheated to a temperature below about 800° F. it is not necessary to preheat in a reducing or inert atmosphere, but if the graphite mold is to be preheated to a temperature above 800° F., it is essential either to preheat under vacuum conditions or in an inert or reducing atmosphere, as in an atmosphere of hydrogen or carbon monoxide, otherwise graphite will burn when exposed to oxidizing conditions. Since most precision cast metals have a melting point in excess of 800° F., it is desirable to carry out metal pouring by conventional vacuum casting techniques wherein the graphite mold, with or without preheat, is enclosed within a vacuum chamber in communication with a metal melting furnace whereby a vacuum can be drawn in the chamber in which the mold is mounted to evacuate the chamber prior to metal pouring. The mold

and the metal cast therein are preferably maintained under vacuum until the metal has solidified or the assembly has cooled to a temperature below 800° F. Thereafter, the assembly can be removed from the vacuum chamber for further processing.

An important concept of this invention resides in the ability to fabricate castings of refractory metals and alloys of extremely high melting point or metals which are subject to rapid oxidation when at elevated temperature, as represented by such metals as zirconium, silicon, tantalum, titanium, and the like. This technicological advance stems in part from the new and novel characteristics made available from a graphite mold of the type produced by the practice of this invention coupled with the means and method by which the molding process is carried out. Amongst many other desirable characteristics, the graphite mold embodies a desirable degree of porosity; high temperature stability; high dimensional stability; a desirable balance of high strength and tear strength, whereby the mold maintains shape during metal pouring at high temperature without so much strength as would cause tearing of the molded product responsive to differential shrinkage upon cooling; high heat conductivity for rapid cooling or controlled heat transfer for the development of best conditions in the metal poured; and the ability to maintain an inert or reducing atmosphere for the protection of the metal while in a molten or highly oxidizable state, and finally in the ability to effect clean and complete separation of the mold either by fracture of the graphite mold or by oxidation of the mold to weaken or to burn out the structure.

This phase of the invention will be described with reference to the molding of titanium, it being understood that others of the refractory or high melting point metals or other metal subject to rapid oxidation at elevated temperatures may be similarly processed.

While the graphite mold can be used in vacuum molding without processing the mold to render it inert to reaction with the metal cast, the porous graphite mold can be so processed to enable metal pouring without vacuum or further to enhance the vacuum molding of molten metals.

In processing to achieve an inert state, the graphite mold is packed in graphite chips and heated to elevated temperature. A temperature in excess of 800° F. will be sufficient but it is preferred to heat to a temperature in excess of 1800° F. and more preferably to a temperature approaching the temperature of the molten metal, such as within the range of 1800–2200° F. for 1 to 8 hours. It is desirable to carry out such heating step in an inert and preferably reducing atmosphere. The heated mold is evacuated as in a vacuum chamber, to de-gass the walls of the mold. The mold is thereafter cooled, preferably to about ambient temperature, while the vacuum is still maintained and thereafter the vacuum is released by bleeding in an inert gas, such as argon, or a reducing gas, such as hydrogen, to refill the pores with such inert or reducing gas thereby to purge the mold of oxygen and to block the re-entry thereof. De-gassing in the manner described can be repeated one or more times but such additional purging is not ordinarily required.

The graphite mold, with or without inerting, is transferred to the vacuum pouring furnace and the metal is poured under vacuum into the mold, with or without preheating of the mold. When preheating is employed, it is unnecessary to preheat to a temperature in excess of 800° F. although preheating to higher temperatures may be employed.

The firing of the mold and vacuum pouring can be carried out in the same chamber. The graphite mold can be heated in the vacuum furnace to purge the mold of oxygen and then metal can be poured in the evacuated mold without, but preferably after, first refilling the pores with inert gas.

The poured metal is allowed to cool in the vacuum chamber to a temperature below that at which oxidation

can take place before removal of the mold for exposure of the poured mold to the atmosphere for further cooling.

An important concept of the invention is unique to the type of mold that is produced. While the cast metal produced can be removed by conventional techniques of impacting and shaking to break up the mold and to free the casting and by blasting to remove graphite retained on the surfaces of the casting, the graphite mold of this invention is capable of being cleanly and substantially completely removed to leave a clean casting merely by exposure to high temperature in an oxidizing atmosphere, as by heating in air, whereby graphite is consumed. The entire mold can be caused to be consumed at a temperature above 800° F. in an oxidizing atmosphere but it has been found to be sufficient only partially to burn out the graphite since the remainder can thereafter be easily pulled off for clean removal from the casting.

It will be understood that changes may be made in the details of construction, arrangement and operation without departing from the spirit of the invention, especially as defined in the following claims.

I claim:

1. A dip coat composition for use in forming a mold about a disposable pattern for use in precision casting upon removal of the disposable pattern comprising an aqueous composition consisting essentially of colloidal graphite of less than 1 micron in diameter, graphite flour of less than 200 mesh and the balance water, and in which the colloidal graphite comprises 1.5 to 10 percent by weight of the graphite solids.

2. A dip coat composition for use in forming a mold about a disposable pattern for use in precision casting upon removal of the disposable pattern comprising an aqueous composition consisting essentially of the combination of colloidal graphite and graphite flour and the balance water, and in which the colloidal graphite is present in the dip coat composition in an amount within the range of 0.5 to 5 percent by weight.

3. A dip coat composition for use in forming a mold about a disposable pattern and from which the pattern is removed for use of the mold in precision casting comprising an aqueous composition consisting essentially of graphite in the form of a graphite flour and graphite in the form of colloidal graphite with the colloidal graphite comprising from 1.5 to 10 percent by weight of the graphite solids, an emulsifying agent present in an amount within the range of 0.01 to 0.5 percent by weight of the composition, and the balance water.

4. A dip coat composition as claimed in claim 3 in which the colloidal graphite component is present in the dip coat composition in an amount within the range of 0.5 to 5 percent by weight and in which the emulsifying agent is gum tragacanth.

5. A dip coat composition for use in forming a mold about a disposable pattern and from which the pattern is removed for use of the mold in precision casting comprising an aqueous composition consisting essentially of graphite in the form of a graphite flour and graphite in the form of colloidal graphite with the colloidal graphite comprising from 1.5 to 10 percent by weight of the graphite solids, an anionic surface active agent present in an amount within the range of 0.01 to 0.5 percent by weight and the balance water.

6. A mold for precision casting having walls formed in cross-section of alternate layers wherein one layer consists essentially of a mixture of colloidal graphite and graphite flour with the other layer consisting essentially of a graphite stucco and in which the colloidal graphite is present in an amount within the range of 1.5 to 10 percent by weight of the mixture of colloidal graphite and graphite flour.

7. In the method of producing a mold about a disposable pattern which is removed to define the mold cavity, the steps of wetting the surface of the pattern with an aqueous dip coat composition consisting essentially of

the combination of graphite flour, colloidal graphite, and water, with the colloidal graphite being present in an amount within the range of 1.5 to 10 percent by weight of the graphite solids, covering the surface of the pattern while wet with the dip coat composition with a graphite stucco, repeating the cycle of operations a number of times until a mold of the desired wall thickness and strength is built up about the pattern.

8. In the method of producing a mold about a disposable pattern which is removed to define the mold cavity, the steps of wetting the surface of the pattern with an aqueous dip coat composition consisting essentially of the combination of graphite flour, colloidal graphite and water, covering the surface of the pattern while wet with the dip coat composition with a graphite stucco and repeating the cycle of operations a number of times until a mold of the desired wall thickness and strength is built up about the pattern and in which the colloidal graphite is present in the dip coat composition in an amount within the range of 0.5 to 5 percent by weight.

9. In the method of producing a mold about a disposable pattern which is removed to define the mold cavity, the steps of wetting the surface of the pattern with an aqueous dip coat composition consisting essentially of the combination of graphite flour, colloidal graphite and water, covering the surface of the pattern while wet with the dip coat composition with a graphite stucco, and repeating the cycle of operations a number of times until a mold of the desired wall thickness and strength is built up about the pattern and in which the dip coat composition contains an anionic surface active agent present in an amount within the range of 0.01 to 0.5 percent by weight.

10. In the method of producing a mold about a disposable pattern which is removed to define the mold cavity, the steps of wetting the surface of the pattern with an aqueous dip coat composition consisting essentially of the combination of graphite flour, colloidal graphite and water, covering the surface of the pattern while wet with the dip coat composition with a graphite stucco, and repeating the cycle of operations a number of times until a mold of the desired wall thickness and strength is built up about the pattern and in which the dip coat composition contains an emulsifying agent present in an amount within the range of 0.01 to 0.5 percent by weight.

11. In the method of producing a mold about a disposable pattern which is removed to define the mold cavity, the steps of wetting the surface of the pattern with an aqueous dip coat composition consisting essentially of the combination of graphite flour, colloidal graphite, and

water, covering the surface of the pattern while wet with the dip coat composition with a graphite stucco, repeating the application of the dip coat composition and stucco for a number of cycles with intermediate drying until a mold of the desired wall thickness and strength is built up about the pattern, removing the pattern from the mold, and firing the mold to a temperature in excess of 800° F. in a non-oxidizing atmosphere.

12. The method as claimed in claim 11 in which the mold is fired to a temperature within the range of 800–2200° F. in a non-oxidizing atmosphere.

13. The method as claimed in claim 11 which includes the step of impregnating the mold after firing by exposing the mold to a solution comprising colloidal graphite wherein the graphite has a particle size of less than one micron.

14. The method as claimed in claim 13 in which the mold is impregnated through a number of cycles with intermediate drying to produce a mold having graphite in high density in cross-section.

15. In the molding of cast shapes with refractory metals comprising providing a mold formed of graphite in cross-section comprising layers of colloidal graphite and graphite flour alternating with layers of graphite, stucco, placing the graphite mold in a vacuum chamber, drawing a vacuum on the mold, reducing the refractory metal to a molten state, introducing the molten refractory metal into the graphite mold while still maintaining vacuum conditions, cooling the mold with the refractory metal cast therein to below the solidification temperature for the metal before removing the mold from the vacuum chamber, and then separating the mold from the cast metal product.

16. The molding process as claimed in claim 15 which includes the step of burning graphite from the mold for separation of the mold from the cast metal product by exposing the mold to oxidizing conditions while at a temperature above 800° F.

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MARCUS U. LYONS, *Primary Examiner*.