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MULTI-LAYER SHELL MOLD

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4 Claims. (Cl. 22—193)

This invention relates to a method of making multi-layer shell molds for investment casting and to compositions of matter to be used therein.

The investment-casting process, also known as the precision or "lost wax" casting process, has undergone many improvements over the past decade. Because the process is essentially manual, requiring much handling of individual pieces, and also because of the need to improve the quality of the castings, improvements and simplifications of the process are much in demand by producers of investment castings.

In the investment-casting process an expendable wax or plastic pattern of the object to be reproduced is prepared. This pattern is then covered with a ceramic-type material leaving an aperture for the draining out of the wax pattern by melting after the ceramic material has hardened. The resulting mold thus contains an exact impression of the pattern into which molten metal may be cast. These molds may be either of the massive mold type or the thin shell mold type. The massive mold investment-casting process is cumbersome requiring the use of back-up investment and metal mold supports and has been replaced in certain areas of the casting industry by the thin shell mold process.

The thin shell mold is usually made in the following manner: (1) an expendable pattern is coated with a fine ceramic slurry; (2) dry coarse ceramic particles are dusted on the wet coating; (3) several coats of other ceramic slurries, often varying from basic to acidic coats, are further applied and each is dusted with coarse, dry ceramic particles until a shell thickness of about ¼-inch to ½-inch thick is obtained; (4) the expendable pattern is melted or dissolved out of the mold and the mold is fired and ready for casting.

The above-described process for making thin shell molds is relatively simple compared to the older massive mold techniques; however, the new process also introduces new problems that have hampered the full utilization of the advantages of thin shell molds in the casting industry.

Generally speaking, when the thin shell mold is hard and strong, it is also relatively dense and, therefore, subject to thermal shock cracking. Furthermore, such molds are not porous enough to allow for the escape of entrapped gases that are found in the mold during casting. Conversely, molds that are sufficieintly porous are generally soft and weak and, therefore, subject to cracking in production-line operations or during the pouring of metal.

While the problem of cracked molds is common to both thin shell molds and massive molds, cracks are especially harmful in the thin shell mold because during casting the thermal shock of the molten metal may widen the cracks allowing the metal to escape from the mold creating a hazard to personnel and equipment.

This tendency to crack exists in both the massive and the thin shell molds. Consequently, most producers invest the thin shell moid in an additional backing mixture within a flask to obtain adequate strength and protection when producing castings that are relatively large or when

using pressure casting methods. This, of course, nullifies some of the more important advantages obtained by the use of thin shell molds.

It is the primary object of this invention, therefore, to provide materials and techniques for an improved method of preparing molds having a desirable combination of strength and permeability properties that will reduce or eliminate most of the disadvantages previously mentioned.

It is a further object of this invention to provide means for simplifying the preparation of molds and to make the lost wax process more nearly approach a continuous operation with a high degree of freedom from the hazard of fractured molds.

It is also an object of this invention to provide a thin shell casting mold which produces castings that are superior in dimensional accuracy and surface quality to castings produced by currently used processes.

Other aims and advantages of the invention will be apparent from the following description and the appended claims.

In accordance with the present invention a method for producing thin shell molds is provided which greatly simplifies the preparation of such molds. The process taught by this invention is similar to the conventional investment casting (expendable pattern) process in preparing the wax pattern assembly. Ceramic slurries of a special composition and containing refractory particles are then used to coat the pattern assembly. Four to eight layers of slurry are applied; each is followed with a stuccoing application of refractory particles. The drying time between each slurry application varies from 15 to 45 minutes depending upon ambient temperature, humidity and air currents. The strength of the resultant mold is sufficient so that no further flasking, investing, or other treatment is necessary. Depending on size and configuration of pattern, a minimum of three hours final drying time is required before the molds are fired at 1600 to 2150° F. for 20 to 100 minutes in a single firing cycle. Neither slow heating (or cooling) nor a long firing cycle is required; in fact, neither is recommended for best results.

The total minimum time necessary for mold preparation and casting varies from about 4 hours to about 6 hours. This constitutes a considerable improvement when compared with the mold preparation time of 16 hours to 4 days necessary for the conventional massive-mold investment casting process as previously described, or 10 to 26 hours for many thin shell molds now used in the art.

Two coating materials are provided to be used in the process; one coating material forming an extra-strong but relatively impermeable mold, and the other material giving a more permeable, but less strong mold. The broad ranges of compositions of these two coating materials are given in Tables I and II with the amounts of each ingredient required to make up a sample batch.

TABLE I

Coating Material No. 1

	Broad range
Sodium silicate	1600 to 3000 cc.
Water	2400 to 1000 cc.
Wetting agent	10 to 100 cc.
Octyl alcohol	5 to 50 cc.
Clay	50 to 500 grams.
Alumina (—325 mesh)	15 to 25 lbs.

Coating Material No. 1 contains from about 40 percent to about 75 percent by volume of liquid sodium silicate computed as follows: the volume of water contained in the slurry plus the volume of liquid sodium silicate is considered as 100 percent. The modifying liquids, a wetting agent and alcohol, are present in relatively small quantities and need not be figured in this computation although such additions should be included if they are sizeable, for the minimum volume of liquid sodium silicate present should be about 40 percent by volume of the total liquids present. The clay and alumina additions are not used in determining the percentage of sodium silicate. The alumina refractory material is finely comminuted, having a grain size passing a No. 325 mesh.

The sodium silicate used can be a 35° Baumé sodium silicate having a specific gravity of about 1.33. A sodium silicate having a Na_2O content of 6.75 percent by weight, a SiO_2 content of 25.3 percent by weight, and a water content of about 67.9 percent by weight has been found to be suitable.

TABLE II

Coating Material No. 2

	Broad range
Ethyl silicate	19.5 to 42.0 lbs.
Isopropyl alcohol	42.0 to 16.0 lbs.
Water	1 to 5 lbs.
Hydrochloric acid (concentrated)	10 to 30 cc.

Table II gives only the composition of the liquid constituents of Coating Material No. 2. This liquid formula is mixed and aged for about four hours to insure complete hydrolysis and then combined with the solid constituents shown in Table III. The solid constituents include boro-silicate glass grains or grog having a grain size less than 35 mesh but larger than 80 mesh. These two materials are interchangeable.

TABLE III

Solid Constituents of Coating Material No. 2

	Broad range
Alumina (−325 mesh)	110 to 160 lbs.
Wetting agent	100 to 300 cc.
Boro-silicate glass grains or grog (−35+80)	5 to 8 lbs.

The percentage range of ethyl silicate in Coating Material No. 2 is from 31 percent to 69 percent by weight computed as follows: The water plus ethyl silicate plus alcohol is considered as 100 percent. The smaller amounts of modifying liquids and refractory particle additions are not used in determining the percentage of ethyl silicate.

An ethyl silicate having a silica content of about 40 percent by weight has been found suitable.

A narrower range and also a preferred range of compositions for Coating Materials No. 1 and No. 2 are given in Tables IV and V, respectively.

TABLE IV

Coating Material No. 1

	Aim Preferred	Preferred Range
Sodium Silicate cc.	2,400	1,600 to 3,000
Water cc.	1,600	2,400 to 1,000
Wetting Agent cc.	40	42.0 to 38.0
Octyl Alcohol cc.	20	18.5 to 21.5
Clay grams	200	190 to 210
Alumina (−325 mesh) lbs.	17	18.0 to 16.0

The preferred composition of Coating Material No. 1 also contains from 40 percent to 75 percent sodium silicate computed as above. The preferred aim point of sodium silicate contents is about 60 percent by volume.

Table V contains both the liquid and solid constituents of Coating Material No. 2, an aging time of about four hours being required for the liquid formula before it is mixed with the solid formula. In preparing Coating Material No. 2 the proportions should be preferably adjusted to obtain a specific gravity of about 1.9 to 2.25 grams per cc. for best results.

TABLE V

Coating Material No. 2

	Preferred Composition	Narrower Composition Range
LIQUID FORMULA		
Ethyl Silicate lbs.	27	22 to 35
Alcohol lbs.	20	25 to 12
Water lbs.	3	2 to 4
Hydrochloric Acid (about 37 percent concentrated) cc.	18	15 to 25
SOLID CONSTITUENTS		
Alumina (−325 mesh) lbs.	135	140 to 130
Wetting Agent cc.	240	190 to 290
Boro-Silicate glass grains or grog (−35+80) lbs.	7	8 to 6

The preferred composition range of Coating Material No. 2 contains from about 45 percent by weight to about 69 percent by weight ethyl silicate and the preferred aim point is about 54 percent by weight ethyl silicate computed as before.

After the expendable patterns have been coated with one of the above-described coating materials, a stucco coating is applied according to the methods to be discussed later. Two groups of stucco materials are provided. Group 1 includes the following materials in the indicated grain sizes: boro-silicate glass grains, mullite grains, sillimanite grains, alumina grains, and a highly siliceous refractory material of low thermal expansion marketed under the trade name Nalcast grains by the National Aluminate Corp. (all these grains should be of the size which pass through a No. 35 mesh but are retained on a No. 80 mesh); zircon sand grains, and high alumina refractory grains (these two grains should have a size which pass a No. 50 mesh but which is retained on a No. 325 mesh). The high alumina refractory material is commonly known as grog. Any one or more of the materials listed above may be used as a stucco material and are designated as Group No. 1 stucco material. Zircon sand passing a No. 50 mesh and retained on a No. 200 mesh has been found to be preferable.

Group No. 2 stucco materials include the following materials in the indicated grain sizes: boro-silicate glass grains, zircon sand, mullite grains, sillimanite grains, alumina grains, Nalcast grains (all these grains should be of a size which pass a No. 10 mesh but which are retained on a No. 80 mesh); and high alumina refractory grains or grog which pass a No. 10 mesh and are retained on a No. 100 mesh. While any one or more of the above-listed materials may be used as a Group No. 2 stucco material, a preferred material is grog passing a No. 10 mesh but retained on a No. 50 mesh.

It will be noticed that the Group No. 2 stucco materials contain some larger size grains than Group No. 1 stucco materials. The two groups of stucco materials, as well as the two coating materials, are provided so that different types of shell molds may be produced. In the production of castings that require extra strong molds, the Coating Material No. 1 should be used for all coats (which can vary from 4 to 8 coats), and a Group No. 1 stucco material should be used on the first coat, with a Group No. 2 stucco material applied on all subsequent coats. This process, designated Method A, is not entirely satis-

factory for configurations having sharp inside corners, sharp edges, or very thin sections which are difficult to cast in a mold having low permeability.

When producing castings that require a more permeable mold, Coating Material No. 2 may be used for all coats (from 4 to 8 coats), the first coating stuccoded with a Group No. 1 stucco material, and the subsequent coatings stuccoed with a Group No. 2 stucco material. This process, designated Method B, produces molds which are somewhat weaker than those produced under Method A and should not be used when very large molds are required.

For most applications, the preferred method of preparing molds combines the advantages of Method A and Method B. In this process, designated Method C, the first coating should be made with the preferred composition of Coating Material No. 1 and stuccoed with zircon sand stucco from Group No. 1 stucco materials. The subsequent coatings should be made with the preferred composition of Coating Material No. 2, each coating being stuccoed with the high alumina refractory of Group No. 2 stucco materials. Molds produced in accordance with this process have the best combination of strength and permeability.

In Coating Material No. 1, sodium silicate is used as the binder because it produces a strong physical bond at normal room temperatures and humidities as well as under controlled drying conditions.

A minimum of 40 percent by volume sodium silicate is required and a preferred amount is about 60 percent by volume. The higher sodium silicate content promotes the formation of a complex sodium-alumina-zirconium-silicate glass-like material when heated within the 1600° F. to 2150° F. firing range. The increased concentrations of sodium silicate, which are considerably higher than normally used in the present art, yield definite improvements in the resistance of the shell mold to wash and spalling; also there is improved dimensional control and surface quality of the casting, regardless of the type of metal or alloy that is cast. It is believed that the higher concentration of sodium silicate improves the thermal properties of the mold by lowering the fusion temperature of the first coat, thereby permitting the first coat to yield to the stresses of expansion or thermal shock while the outer coats remain rigid. As a result, the solid constituents may expand freely within the first coat without fracturing the mold as is usually expected when thermal expansion of solid constituents takes place within a hard mass. This theory is sustained by the following experiment wherein various solid materials with varying thermal expansion characteristics are substituted in place of the finely comminuted alumina in the slurry material of Coating Material 1. In a series of tests the materials set forth in Table VI were substituted with no thermal shock failures during casting and castings of equal quality were produced.

TABLE VI

Material:	Coefficient of Thermal expansion × 10^{-7}
Boro-silicate glass	8
Alumina	80–90
Alumina (fused)	79
Mullite	28–42
Zircon	26
Stabilized zirconia	72 (70–1000° C.)
Aluminum titanate	10 (to 1000° C.)

Ethyl silicate is used as the binder for Coating Material No. 2 because it has several advantages over other materials. Hydrolyzed ethyl silicate dries rapidly at normal room temperatures and humidities and may be modified for controlled drying under certain conditions. When slurries are composed as disclosed by this invention, the hydrolyzed solution of ethyl silicate forms a gel when it is applied on the pattern. Then, upon further curing and evaporation (15 to 45 minutes), the gel dehydrates, gives up alcohol, shrinks, and forms a deposit of adhesive silica. Best results are achieved when the subsequent coating is applied before the ethyl silicate gel has completely dehydrated and, therefore, before it has completely shrunk to its lowest volume. After the final slurry application has been made, the mold is cured more completely (3 hours minimum). During the firing stage, the gel shrinks further to its lowest volume, thereby leaving voids into which the solid constituents expand during the firing and casting of the mold. Furthermore, the presence of these voids enhances the permeability of the mold, which, of course, is very beneficial in producing good castings. All of the bond is obtained from the ceramic materials that are used in the slurry, the coarser particles of the stucco and from the amorphous silica from the hydrolyzed ethyl silicate solution. The bond is of sufficient strength so that no fritting or fluxing ingredients are required for additional strength. Some slurries now used in the art usually require fritting or fluxing ingredients to lower the eutectic melting point of alumina and silica to effect a bonding mechanism by fusion.

Table VII shows desired proportions of ingredients of Coating Material No. 2.

TABLE VII

Compositions of Coating Material No. 1

Ingredients	Formula					
	1	2	3	4	5	6
Sodium Silicate, cc.	1,600	2,000	2,400	2,800	3,000	3,200
Water, cc.	2,400	2,000	1,600	1,200	1,000	800
Alcohol, cc.	18	19	20	21	22	22
Clay, grams	190	195	200	205	207	210
Alumina, lbs.	18	18	17	17	16	16
Wetting Agent, cc.	42	41	40	39	38	38
Percentage by volume of Sodium Silicate	40	50	60	70	75	80

The compositions shown in Table VII contain a wetting agent. Any commercial wetting agent may be employed in the coatings. "Tergitol" has been found suitable. The presence of a wetting agent insures proper coverage of the coating on the wax patterns and also on the series of the subsequent coats.

Octyl alcohol is employed as a defoaming agent in Coating Material No. 1 to eliminate or minimize entrapped air within the slurry. Other defoaming agents may be used however. Clay is included in the mix to increase the viscosity of the slurry and improve its suspension properties.

The formulas shown in the right extremity of Table VII, Formulas 5 and 6, will produce the strongest shell coating when used in accordance with Method A. In making a shell mold according to Method A a Coating Material No. 1 composition is used for all coats, Formula No. 3 being preferred. Zircon sand passing a No. 50 mesh and retained on a No. 200 mesh should be used as a first stucco coating material. After each subsequent application of liquid formula, a high-alumina refractory material passing a No. 10 mesh but retained on a No. 50 mesh should be used. The number of coats should be from 4 to 8 with a drying time between each application of from 15 to 45 minutes depending on the ambient temperature. A final drying or curing time of at least three hours is required after which the molds may be fired at a temperature of from about 1600° F. to about 2150° F. for from 20 to 100 minutes. In this single firing cycle the expendable material is melted and drained out and the mold is fired.

In Table VIII several prepared compositions of Coating Material No. 2 are shown. Formulas 6 and 7 will yield the strongest mold and Formulas 1 and 2 will yield the

most permeable mold. Formula 4 is preferred where a mold having the best combination of strength and permeability is desired.

TABLE VIII

Compositions of Coating Material No. 2

Ingredients	Formula						
	1	2	3	4	5	6	7
Ethyl Silicate, lbs.	12	17	22	27	32	37	42
Alcohol, lbs.	15	20	25	20	15	10	5
Water, lbs.	3	3	3	3	3	3	3
Acid, cc.	18	18	18	18	18	18	18
Wetting agent, cc.	240	240	240	240	240	240	240
Alumina, lbs.	148	144	140	136	132	128	124
Boro-Silicate Grains, lbs.	7	7	7	7	7	6	6
Percentage by weight of ethyl silicate	24	34	44	54	64	74	84

When producing castings that require a highly permeable mold according to Method B, all the coats can be made with a formula such as No. 2 or No. 3 of the Coating Material No. 2. The first coat should be preferably stuccoed with zircon sand passing a No. 50 mesh and retained on a No. 100 mesh and each subsequent coat should preferably be stuccoed with high alumina refractory grains passing a No. 10 mesh but retained on a No. 50 mesh. The drying times and firing temperatures and times are the same as used in Method A.

The size and configuration of the pattern assembly will determine the specific need for either high strength or high permeability and enable the selection of the proper formula. Shell molds having the best combination of strength and permeability can be produced in accordance with Method C using Formula No. 3 of Coating Material No. 1 for the first coat and a zircon sand stucco followed by coats of Formula No. 4 of Coating Material No. 2 and stucco coats of the high alumina refractory grains described above. The drying times and firing procedure are the same as used in Methods A and B.

It is to be noted that some modifications may be made in the three methods described above without departing from the essentials of the invention. For example, more than eight coatings may be applied, or the curing and/or firing times may be considerably increased without harmful effects.

Rapidly heating the cured mold to a temperature of from 1600° F. to 2150° F. does not cause thermal cracking. Instant heating is recommended as a means to avoid cracking that may be caused by the thermal expansion of the pattern material when it is permitted to heat slowly. The firing temperature range, 1600° F. to 2150° F., is considerably below the temperature required for an eutectic reaction between the alumina and silica.

Shell molds produced in accordance with the above-described methods and compositions have sufficient strength to withstand the erosive force of the molten metal poured into the shell, thereby guaranteeing a smooth-surfaced casting. The shell molds also withstand normal handling operations, especially in production-line systems without fracturing and, in fact, are sufficiently strong to allow the use of pressure casting methods.

The shell molds have sufficient permeability to permit the rapid elimination of trapped air in the mold and also gases that may be formed in the mold during firing or casting.

The dimensional stability of these molds is such that rejections cause by out-of-tolerance dimensions of the castings are reduced to a negligible amount.

The rapid curing properties of the mold materials afford a time-saving improvement over prior investment mold making processes which required a 2- to 24-hour drying and curing time between each successive coating and stuccoing operation.

What is claimed is:

1. A method for preparing a multi-layer shell mold characterized by a good combination of strength and permeability and capable of use without support comprising preparing a first coating solution consisting essentially of the following ingredients in the indicated proportions:

Sodium silicate solution, s.g. 1.33	1600 to 3000 cc.
Water	2400 to 1000 cc.
Wetting agent	10 to 100 cc.
Defoaming agent	5 to 50 cc.
Clay	50 to 500 grams.
Alumina (−325 mesh)	15 to 25 lbs.

and a second coating solution consisting essentially of the following ingredients in the indicated proportions:

Ethyl silicate	19.5 to 42 lbs.
Alcohol	42 to 16 lbs.
Water	1 to 5 lbs.
Conc. hydrochloric acid	10 to 30 cc.
Alumina	110 to 160 lbs.
Wetting agent	100 to 300 cc.
Boro-silicate glass grains (−35+80)	5 to 8 lbs.

applying a coating of said first solution to an expendable pattern, stuccoing said coated expendable pattern with a granular refractory material, and thereupon alternately applying coatings of said second solution and stuccoing with a coarser granular refractory material to build up a shell of sufficient thickness, and then removing the expendable pattern material and firing the resulting multi-layer shell mold to hardness.

2. A multi-layer shell mold made in accordance with the process of claim 1.

3. A method for preparing a multi-layer shell mold characterized by a good combination of strength and permeability and capable of use without support comprising preparing a first coating solution consisting essentially of the following ingredients in the indicated proportions:

Sodium silicate solution, s.g. 1.33	1600 to 3000 cc.
Water	2400 to 1000 cc.
Wetting agent	42 to 38 cc.
Octyl alcohol	18.5 to 21.5 cc.
Clay	190 to 210 grams.
Alumina (−325 mesh)	18 to 16 lbs.

and a second coating solution consisting essentially of the following ingredients in the indicated proportions:

Ethyl silicate	22 to 35 lbs.
Alcohol	25 to 12 lbs.
Water	2 to 4 lbs.
Conc. hydrochloric acid	15 to 25 cc.
Alumina (−325 mesh)	140 to 130 lbs.
Wetting agent	190 to 290 cc.
Boro-silicate glass grains	8 to 6 lbs.

applying a coating of said first solution to an expendable pattern, stuccoing said coated expendable pattern with a granular refractory material, and thereupon alternately applying coatings of said second solution and stuccoing with a coarser granular refractory material to build up a shell of sufficient thickness, and then removing the expendable pattern material and firing the resulting multi-layer shell mold to hardness.

4. A method for preparing a multi-layer shell mold characterized by a good combination of strength and permeability and capable of use without support comprising preparing a first coating solution consisting essentially of the following ingredients in the indicated approximate proportions:

Sodium silicate solution, s.g. 1.33	2400 cc.
Water	1600 cc.
Wetting agent	40 cc.
Octyl alcohol	20 cc.
Clay	200 grams.
Alumina	17 lbs.

and a second coating solution consisting essentially of the

following ingredients in the indicated approximate proportions:

Ethyl silicate	27 lbs.
Alcohol	20 lbs.
Water	3 lbs.
Conc. hydrochloric acid	18 cc.
Alumina	135 lbs.
Wetting agent	240 cc.
Boro-silicate glass grains (−35+80)	7 lbs.

applying a coating of said first solution to an expendable pattern, stuccoing said coated expendable pattern with a granular refractory material, and thereupon alternately applying coatings of said second solution and stuccoing with a coarser granular refractory material to build up

a shell of sufficient thickness, and then removing the expendable pattern material and firing the resulting multilayer shell mold to hardness.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,077,648 February 19, 1963

Frank R. Sutherland

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 24, for "Coating Material No. 2" read -- Coating Material No. 1 --.

Signed and sealed this 17th day of September 1963.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents