

Nov. 29, 1960

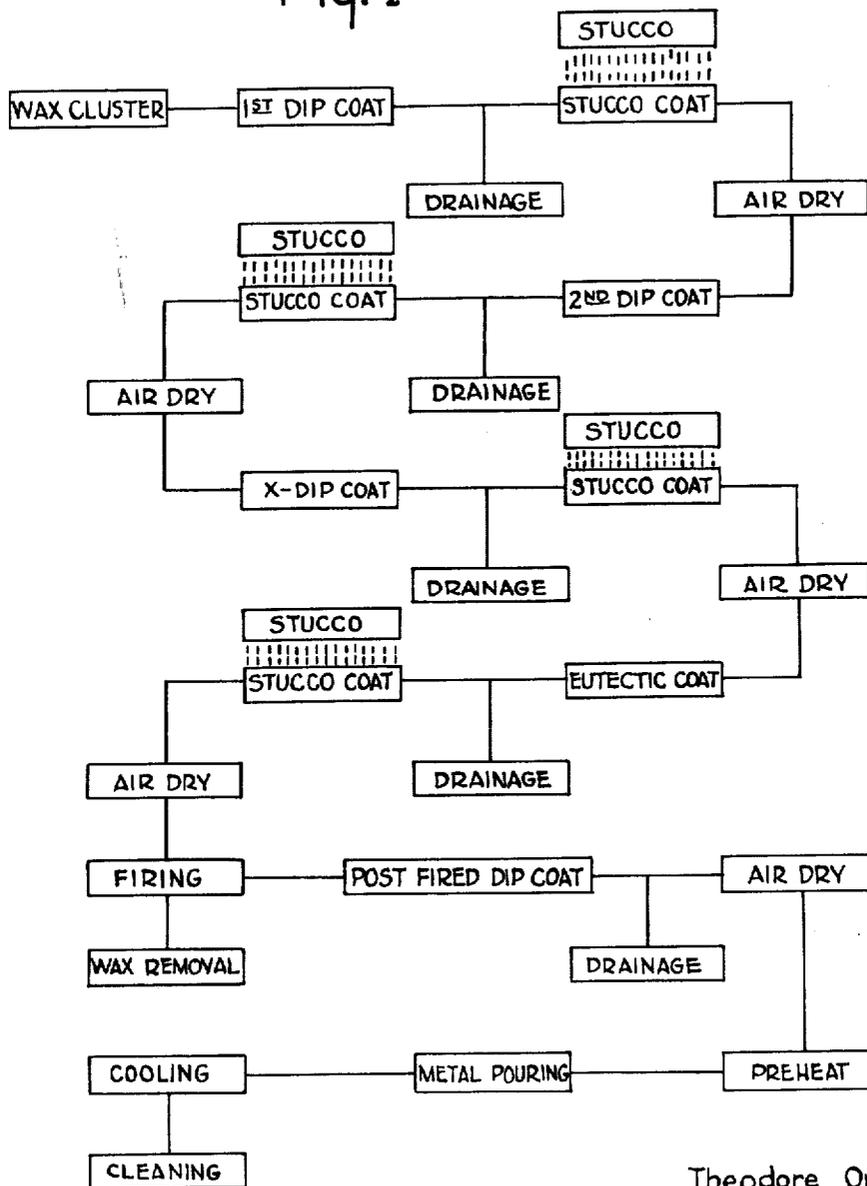
T. OPERHALL ET AL
CERAMIC METAL CASTING PROCESS

2,961,751

Filed Jan. 13, 1958

3 Sheets-Sheet 1

Fig. 1



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3 Sheets-Sheet 2

Fig. 2

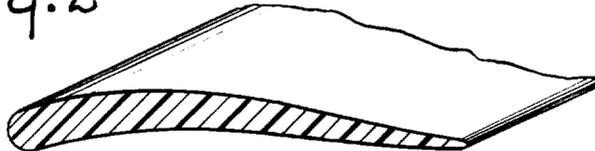


Fig. 3

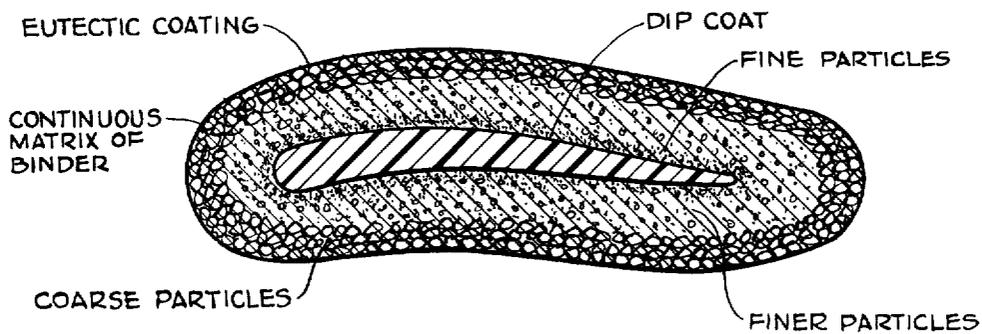
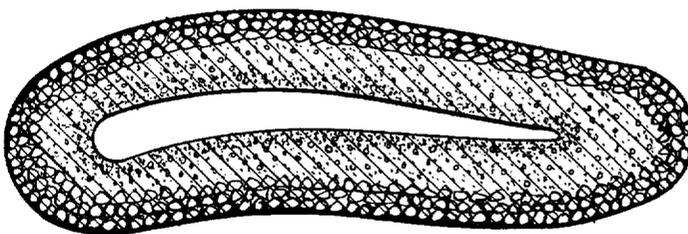


Fig. 4



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3 Sheets-Sheet 3

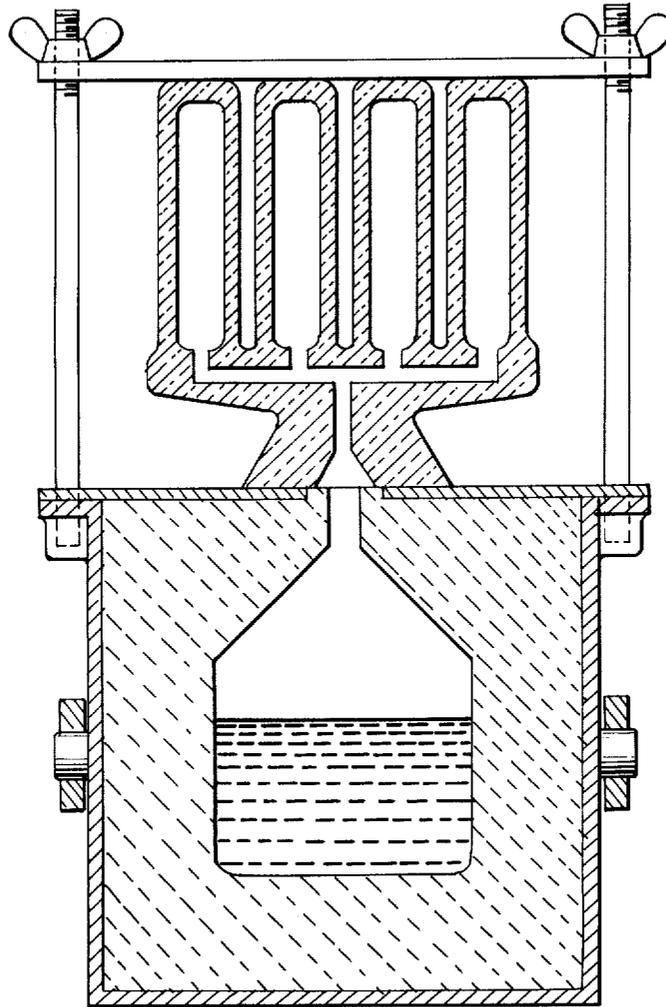


Fig. 5

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CERAMIC METAL CASTING PROCESS

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17 Claims. (Cl. 22—196)

This invention relates to the fabrication of metal castings and it relates more particularly to a metal casting process and materials for use in same embodying some of the elements of an investment casting process with some of the elements of a shell molding process while eliminating many of the limitations of each of the processes to provide a new and improved procedure for the production of metal castings.

Both the investment casting process and the shell molding process are well known to those skilled in the art such that detailed description thereof by way of introduction shall be unnecessary here. Suffice it to say that the investment casting process finds objections in the field from the standpoint of the high cost of materials required in the preparation of the investment and mold for casting; in the large amount of highly skilled labor required for preparation of the wax patterns and the mold, and in the utilization thereof in the casting process, and in the high percentage of scrap which generally characterizes the investment process for the production of metal castings thereby to prevent reduction in cost of castings so produced.

While shell molding with an organic resinous binder eliminates or rather minimizes some of the more objectionable features of the investment casting process, such shell molding process, as it is practiced today, has other characteristics which are objectionable from the standpoint of the desire to produce acceptable castings at high yield with a minimum amount of labor, materials and cost.

Thus it is an object of this invention to provide a new and improved method for the production of metal castings and it is a related object to provide new and improved materials for use in the practice of same.

More specifically, it is an object of this invention to provide a new and improved metal casting process which, while embodying some of the desirable features of the shell molding and investment casting processes, eliminates many of the undesirable characteristics of each and, in addition, provides means whereby a higher yield of good castings can be achieved at less cost from the standpoint of the cost of materials, the amount of labor, time and space, as well as equipment required for manufacture.

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

Fig. 1 is a flow diagram of the process embodying the features of this invention starting from the cluster of wax patterns to the completion of the mold for pouring the metal castings;

Fig. 2 is a perspective elevational view in partial section of a wax cluster employed in the practice of this invention;

Fig. 3 is a perspective view of the cluster shown in Fig. 2 with the castings applied thereon in accordance with the practice of this invention;

Fig. 4 is a perspective view similar to those of Figs. 2 and 3 of the shell mold after the baking operation to re-

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move the wax and to mature the ceramic materials, and Fig. 5 is a schematic sectional elevational view of the metal melting furnace and the mold clamped thereon.

The invention will hereinafter be described with reference to an illustrative practice of the invention, it being understood that variations may be made within the skills of the art.

Preparation of the cluster

To the point where a cluster 10 is formed of the wax patterns 12 mounted between wax runners 14 in communication with a wax spout in the form of a crucible 16, the process is almost identical with the conventional investment casting processes as defined in the Collins Patent No. 2,380,945, Feagin et al. Patents Nos. 2,439,207, 2,441,695 and 2,521,839, and in the Operhall Patent No. 2,806,271.

Dip coating composition

8000 cc. colloidal silica
(30% grade)
(specific gravity 1.198)
165 pounds zircon
(99% through 325 mesh)
(65–67% ZnO₂, 34–32% SiO₂)
6150 cc. water
110 grams sodium fluoride

Application of first dip coat

The cluster 10 of wax patterns 12, carried by a handle 30 embedded in the crucible defining the pouring spout 16 of the cluster, is first inspected to remove dirt, wax flakes and other objects which may have adhered to the surfaces of the wax patterns and, if allowed to remain, would impair the preparation of a good mold, thus leading to an imperfect casting. The cleaned cluster is then immersed into the slip in a manner to coat all of the surfaces of the cluster with the exception of the lip of the crucible. To promote the removal of bubbles from the cluster design, it is desirable to rotate the cluster while immersed in the slip.

When fully coated, the cluster can be removed from the tank to drain. During drainage, the cluster can be inspected to detect air pockets which can be eliminated by directing a stream of air onto the deficient portions and thereafter allowing the slurry of the dip coat to flow onto the blown area. 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 to gel or dry to the extent that a good stucco coat cannot be applied.

First stucco coat

Stucco combination—Alundum (100% through 50 mesh with less than 3% through 100 mesh—better than 90% between 60 and 80 mesh)

Application of stucco coat

After the uniformity of coating has been achieved in the first dip coat and dripping from the patterns has become minimized, the stucco is sprinkled onto the wet coating of the cluster while constantly changing the position of the cluster substantially uniformly to cover the dip coat with a layer of the stucco while, at the same time, minimizing flow of the dip coat whereby non-uniformities might otherwise develop. In practice, the stucco particles will be rained down from above through a screening member constantly being fed by a vibratory feeder to remove foreign matter from the Alundum particles while the particles are sprinkled over an area to give more uniform and complete coverage. The stucco will adhere to the wet coating of the slurry and will become par-

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tially embedded in the slurry to become integrated with the coating formed on the cluster of wax patterns.

If the dip coat is adjusted to enable gelation to take place within a very short period of time, greater than the time required for drainage and stuccoing, the stucco cluster need not be set aside for drying. However, it is preferred to slow the gelation of the dip coat so that sufficient leeway is available for the desired drainage and stucco application and to enable correction for deficiencies which might exist with respect to one or the other. Thus, it is desirable to provide for an air dry in the amount of from 10–25 minutes and preferably from 10–15 minutes. It will be understood that the time of drying may be extended indefinitely beyond the preferred minimums described without harm to the structure.

Second dip coat

The composition of the second dip coat slip is substantially the same as the first. In practice, use is usually made of the first dip coat slip. Application of the slip to provide a second dip coat on the stuccoed cluster is achieved in a manner similar to that of the previous first dip coat.

Second stucco coat

Stucco combination—Alundum (3–60 mesh with less than 3% through 70 mesh)

After the second dip coat has been suitably drained, the coarser particles of stucco are sprayed over the wet surfaces of the second dip coat to incorporate the Alundum particles into the coating to form a part of the composite mass and to lock the coatings into each other. When suitably covered, the cluster is set aside or hung for a short time to set the binder.

Further dip coat slips

The composition of the third and additional dip coat slips corresponds to the composition of the first and second dip coat slips. Use is usually made of the first or second dip coat slips which probably have become contaminated by the presence of coarse particles of Alundum or stucco removed from the cluster during previous dips. This is because a slip with coarse particles of the type described would be unsuitable for use as a first dip coat because of the undesirable effect that the coarse particles would have on the mold surface and on the casting produced within the mold. In commercial practice, where the dip coat compositions will be consumed at a relatively rapid rate, the separation as between the first and subsequent dip coats is not so important, but it is preferred to go up the scale rather than down if any changes are made.

The third and additional dip coat is achieved in essentially the same manner as the first and second dip coats by immersion of the cluster with the first and second stucco coats into the slurry while turning the cluster or by revolving the drum in which the slurry is contained. After coating, the cluster is drained while turning to provide a uniform coating of the slip over the entire surface with the exception of the lip of the crucible.

Further stucco coats

Stucco—tabular alumina

For the third and additional stucco coats use is preferably made of tabular alumina in the form of coarse particles ground to pass through a 14 mesh sieve and to be retained on a 20 mesh sieve with less than 10% through a 50 mesh sieve and less than 1% on a 6 mesh sieve.

Application is made as before onto the wet layers of the previous dip coat after proper drainage and distribution. After each coat, the coated wax pattern or cluster of patterns is allowed to dry or set to the gelled stage prior to the next series of coatings. If gelation occurs almost immediately upon application of the stucco coat, the drying step may be dispensed with. Usually from

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5–10 or more dip and stucco coats of the type described may be applied in series onto the wax cluster.

Eutectic composition

- 5 8000 cc. colloidal silica
(CaO, <6%)
(specific gravity 1.198)
- 165 pounds zircon
(99% through 325 mesh)
- 10 (65–67% ZnO₂, 34–32% SiO₂)
- 6250 cc. water
- 115 grams sodium fluoride
- 18.5 pounds feldspar
(K₂O, <8%)
- 15 (CaO, <6%)
(ZnO, <9%)
(Al₂O₃, 16–19%)
(SiO₂, 60–63%)

20 The eutectic coating composition is similar in formulation and preparation to the previously defined dip coat with the exception of the Feldspar which is added together with the zircon flour to the mixture.

The eutectic coating is applied in a manner quite similar to the dip coats. The stucco cluster is immersed in the slip with relative movement between the slip and cluster to achieve more uniform distribution and to eliminate as much of the air pockets as possible. The coated cluster is then removed from the slip and the excess eutectic coating composition is allowed to drip from the cluster while turning the cluster to secure a desired uniform coating on the surfaces.

After the eutectic coating has been suitably drained, it is stuccoed as in the additional stucco coats described and then the cluster is allowed to air dry. Sufficient air drying will take place within 16 hours at ambient temperature and the drying time can be shortened considerably by using a dehumidified atmosphere. It is possible under suitable controlled conditions completely to dispense with the air drying step and proceed almost immediately to the baking or firing operation in the preparation of the mold but it is preferred to make use of a drying and aging period sufficient, at least, to remove free moisture, when present.

Firing the cluster

The cluster having the predetermined number of dips and stucco coats and one or more of the eutectic coats on the surface is subsequently fired by exposure to a temperature of 1800° F. for from 3–30 minutes, depending greatly upon the mass of material which is being subjected to the firing and baking operation. The cluster is usually suspended with the crucible facing downwardly in the furnace so that the wax can drain from the mold as it is reduced at these temperatures to molten state. The great majority of the wax from the patterns and parts will be removed by drainage while in the molten state and the residue which remains in the mold will be rapidly burned out at the temperature conditions existing.

60 The fired product can thereafter be set aside to cool. The lip will be ground down to provide a flattened surface adapted more substantially to conform with the face plate of an invertible furnace in which the metal is reduced to the molten state so that the finished mold can be clamped to the face plate of the furnace to enable the metal to be poured directly into the shell mold by inversion. In practice, it is preferred to grind down the lip before the firing step.

70 While a shell mold suitable for pouring will be secured at the conclusion of the firing step used to free the shell of the wax patterns, gates and other parts and to mature the ceramic materials making up the shell mold, some expansions and contractions do take place which may result in the formation of small cracks and fissures. Thus it is preferred, in accordance with the

practice of a concept of this invention, to provide for additional vitrification in the outer portion of the mold and to increase the strength of the mold while at the same time sealing the cracks and fissures by the application of another eutectic coating to the outer surface of the shell mold subsequent to the firing operation. This builds up an additional concentration of Feldspar and the like lower melting ceramic which is barred by the previous layer from deep penetration of the mold and thus remains more concentrated on the surface where it can provide vitrification and where it can heat seal the pores or cracks in the mold.

The post-fired coat corresponds to the eutectic coating and application is the same as in the application of the eutectic coat prior to the firing operation. When a post-fire coat is applied, the coated shell is set aside to dry and the ceramic is matured as an incidence to preheating of the mold to the temperature desired for pouring. For this purpose, the mold is usually preheated to a temperature within the range of 1600–2200° F. and preferably to a temperature within the range of 1700–1900° F. and is then clamped to the furnace for turning over to pour the metal into the heated mold. One of the novel characteristics of a mold prepared in accordance with the practice of this invention resides in the ability to preheat the mold for an extended period of time, as for days, at the temperature conditions described without noticeable effect from the standpoint of “slumping” or the type of vitrification which is characteristic of systems heretofore employed.

Pouring

Prior to pouring the mold can be very carefully and completely inspected to eliminate imperfect molds which might otherwise produce metal castings incapable of use. The ability carefully to inspect the molds at this stage, prior to pouring, materially reduces scrap loss by comparison with the investment casting process wherein the mold cannot be inspected so that any imperfections in the mold will remain hidden until their presence is disclosed by the unacceptable castings that are produced.

Molds prepared in accordance with the practice of this invention are characterized by sufficient strength to enable use as a shell without investment to be clamped as an investment mold to the furnace for pouring. The mold can be clamped to the furnace without additional support to pour the molten metal therein as by reversal of the position of the furnace as described in the Operhall Patent 2,806,271. The mold retains its strength under room or elevated temperatures so that the metal can be poured while the mold is cold but preferably after the mold has been preheated to elevated temperature, such for example as a temperature of 1600–2200° F. to facilitate flow of the metal into innermost regions of the mold and to insure the production of suitable castings.

After the metal has been poured, the poured mold is removed from the furnace and set aside for solidification of the metal. Upon proper solidification, the mold can be broken up to remove the casting and then the latter can be processed in the usual manner for separation, cleaning, inspection and packaging to provide a finished product.

In accordance with one of the further concepts of this invention, it has been found that the conformity of the castings to the mold and the physical and mechanical properties of the casting can be materially improved if, instead of allowing the cast mold to cool in the open atmosphere, the cast shell mold is housed within an insulated container whereby cooling is achieved at a slow and controlled rate for solidification and cooling of the poured metal. In the alternative, the cooling rate can be slowed under controlled conditions by placing the poured mold in the housing and filling the space about the mold with a flowable insulating material such as par-

ticles of exfoliated mica, bloated silica, Santocel and the like. Still further, the rate of cooling to the solidified state can be retarded by placing the poured mold in a heated space, such as a furnace, in which the temperature of the atmosphere can be controlled.

Having previously described the process from the time that the wax patterns are assembled in the cluster to the pouring of the molds, detailed description will now be made of concepts embodying additional features of this invention.

The dip coat compositions may deviate quite widely from the compositions set forth in the foregoing description since they may correspond to the formulations conventionally employed as a base for the application of stucco coats in conventional investment casting processes as defined in the aforementioned patents.

The improvements embodying the concepts of this invention find their support, however, in a combination which makes use of zircon flour as a filler in the dip coat compositions by way of displacement of flint or silica flour which is usually employed. It has been found that silica flour is subject to large inversions during temperature change between room temperature and 2000° F. whereby large contractions and expansions are caused to take place which introduce stresses within the mold that cause deterioration or destruction. With silica, as with other materials, if the inversion stages are traversed quickly, cracks are formed in the mold part through which cast molten metal can escape. This condition would be highly objectionable in an investment casting, let alone a system wherein the mold part is adapted to be clamped to the furnace for pouring without investment or other protective covering.

Both the alumina, used as the stucco, and the zircon used as the filler in the dip coating compositions embodying features of this invention have been found to be relatively free of these inversion characteristics by comparison with silica flour or silica. The expansion and contraction characteristics of zircon and of alumina are so low by comparison with other materials which have usually been employed, that the materials can be heated up rapidly to elevated temperature for maturing the mold or for preheating the mold without endangering the mold by reason of extreme expansions and contractions. It is for this reason that the wax pattern with the described stucco coats thereon can be introduced into a furnace maintained at a temperature as high as 1800–2200° F. to achieve rapid heat-through of the shell for removal of the pattern and for proper maturing of the ceramic materials within the space of 3–30 minutes. This is to be compared with the heating and baking cycle of 14 hours or more heretofore required for conventional investment molds. Thus the time factor in mold preparation can be greatly reduced and the output per unit space can be greatly increased thereby to conserve on the amount of fuel, equipment and space required for the preparation of molds in accordance with the practice of this invention.

By way of further improvement in the process of mold preparation secured by the practice of this invention, more rapid heat-through enhances removal of the wax pattern and parts without endangering the mold. Slow heating of the molds, as necessitated by the conventional investment casting process, permits the wax pattern and parts to become heated through before elevated in temperature to a molten state whereby expansions are caused to take place while the wax pattern and parts are still in a non-flowable condition and fully confined within the investment. Expansion of the wax patterns while still in a solidified state results in the development of tremendous forces which often lead to loss in dimension of the mold and sometimes to the destruction and deterioration thereof to provide imperfections which cannot be determined prior to the removal of the castings from the mold. The more rapid heat-through permitted by the concepts embodying features of this invention provides for an entirely different

operation. The outer portions of the wax pattern and parts are reduced to a molten state prior to heating up the interior portions of the wax patterns and parts so that the wax in the outer portions can be eliminated from the mold prior to heating through the pattern. As a result, space is made available for subsequent expansions which take place upon heating up of the patterns and parts to minimize the development of destructive forces in the mold.

While silica can be used, as in conventional dip coating compositions, it has been found that it is possible to make use of much more rapid heating for maturing and preheating the mold when zircon is employed instead of silica as the filler in these compositions. This enables better control over the casting process when used for high temperature alloys. Silica also comprises a basic refractory which fuses within the temperature range of 3100-3180° F. and which is capable of reaction with the hot metal to develop a slaggy condition that enables silica to be washed from portions of the mold. This leaves an indefiniteness in some portions of the mold and the slagging off of the silica provides for contamination of the metal casting to produce an undesirable and unacceptable product. On the other hand, by using zirconium or zircon as the filler, temperatures up to 4000-4600° F. can be employed before fusion. Reaction conditions for slagging off are substantially avoided thereby to maintain dimensional stability and mold contour for the production of good castings, even with high temperature alloys. The combination of conditions of zircon filler and high temperatures for more rapid maturing of the mold and for casting high temperature alloys are thus employed to improve the casting process and the preparation of molds therefor.

Instead of zircon, use can be made of finely divided particles of flours of alumina, titania, stabilized zircon, fused quartz, thoria, chromite, sillimanite, mullite, magnesia, vycor glass, or the like materials having similar inversion characteristics, good heat-shock properties, high fusion temperature and relatively low expansion characteristics at elevated temperatures within the range from room to 2200° F. It will be understood that the binder component of the slip may comprise other conventional binders employed in the preparation of the stucco coats on wax patterns or patterns formed of other low melting materials employed in investment castings. When such other binder systems are employed, the zircon and the like filler can be incorporated in the amounts previously described.

With reference to the dip coat slips, it is desirable to make use of a fresh slip for the first dip coat since the initial coating is more critical from the standpoint of thickness and character and better controls are available in a newly prepared batch. As a first dip coat, it is desirable to provide for a thickness on the patterns which will enable the stucco to enter into the coating without penetration all the way through to the inner face of the mold. If the coating is too thick, the extra layer at the inner face will not be mechanically held strong enough to prevent separation from the rest of the mold so that the inner layer of the dip coat can be pulled off under certain conditions to cause spalling. If the dip coat film is too thin, the stucco will penetrate through to cause the slip to flow into the crevices between the stucco particles and leave a rough inner face against which the metal is cast. Thus it is desirable to provide for a balance between film thickness and stucco.

For this purpose, it has been found best to provide for a film thickness in the first stucco coat of about 5-10 mils with about 20 mils as a maximum and about 3-4 mils as a minimum and it is desirable to make use of a stucco in a first stucco coat of about 60-80 mesh material. If the mesh size of the stucco is considerably larger, capillary actions developed will operate to bleed moisture from the dip coat composition and leave voids

in the face of the coating. These will be filled by the cast metal and appear as pimples in the final product. On the other hand, if the stucco is too small, such for example as finer than 120 mesh, the stucco fails to develop the mechanical lock desired between the first and second dip coats and often leads to spalling. In general, the balance between the mesh size of the stucco and the thickness of the dip coat can best be determined by trial and error but it will usually fall within the limitations described. The coverage of the dip coat subsequent to the first is enhanced if the stucco coat previously applied is pre-wet as by a wash coat formed of the dip coat composition markedly reduced in viscosity. Considerable benefit is derived when a pre-wet is employed in advance of the use of a dip coat of higher viscosity than employed in previous dip coats.

For the second stucco coat, it is desirable to make use of a material of about 50 mesh. Material larger than 35 mesh is too coarse and permits air pockets to form with possible metal break-through. When less than 100 mesh, it becomes more difficult to develop the desired mechanical interlock between layers. The stucco for the third and subsequent coats is preferably selected of materials within the range of 14-28 mesh. Larger mesh materials can be employed but it is undesirable to exceed ¼ inch material. Finer materials can be employed consistent with the desire to develop an adequate mechanical lock. Instead of Alundum, use as a stucco coat can be made of zircon, sillimanite, mullite, vycor glass, thoria, chromite, magnesia and the like materials having good heat-shock, good refractory characteristics, low expansion rate and expansion and contraction characteristics close to those of the filler in the dip coat.

An important concept of this invention resides in the means for providing an outer portion in the built-up shell which is capable of insipient fusion or a stage of vitrification at temperatures below the vitrification temperature of the zircon to provide a skin barrier which has maturity at lower temperature to form a protective cover; heal any fractures or cracks which might develop in the mold during burning out, preheating and particularly during pouring of the metal, and markedly to strengthen the mold to impart mass integrity which enables use of the shell mold without support for casting molten metal therein, with or without the accompaniment of pressure.

Briefly described, the characteristics are achieved by the formulation of an outer coating of the shell mold with Feldspar presented as a component of the filler in the dip coat. Feldspar vitrifies at a temperature starting at about 1000° F. and continues on up to a temperature of about 2200° F. Thus the Feldspar vitrifies alone and in combination with the siliceous materials present at the temperature conditions existing during firing and preheating to form a eutectic ceramic which is capable of sealing the pores and cracks which are present or which otherwise form in the mold shell during firing, preheating or metal pouring.

As a result of the sealing characteristics made available by the Feldspar in the outer eutectic coat or coats, the cracks are blocked before metal can flow there-through during pouring with the result that the mold is saved, metal is saved and a higher yield of product is secured from the total of the metal poured. Scrap loss has been reduced from values as high as 40-50 percent to an average of a few percent by the employment of the concepts forming the subject matter of this invention.

The eutectic operates as a ceramic flux to secure the particles of stucco in the mold markedly to strengthen the mold shell to the extent that the mold can be clamped on to the furnace for pouring the metal without investment or otherwise supporting the mold and to the extent that it is capable of withstanding normal forces existing in normal handling and clamping as well as internal

forces of the liquid, heat and pressures which might be employed in combination with metal pouring.

It is desirable to make use of an amount of Feldspar capable of imparting the desired strength characteristics described but it is undesirable to make use of such concentration as will lead to excessive diffusion into the mold or will cause the development of hot tears. Feldspar in amount less than 0.05 part per one part by weight of zircon or other filler in the dip coat has been found to be insufficient to impart the desired strength characteristics. When the amount of Feldspar exceeds 0.25 part per one part by weight of zircon or other filler, the mold becomes so strong that it will lead to hot tears in operation and excessive diffusion into the mold may occur. It is preferred to make use of the Feldspar in an amount within the range of 0.08-0.15 part by weight of the Feldspar to one part by weight of the zircon or other filler in the dip coat or about 8-15 percent by weight of the ceramic solids of the dip coat.

In operation, the Feldspar has a tendency progressively to diffuse inwardly during firing. Since it is undesirable to have the Feldspar penetrate into the inner surfaces of the mold, the time and temperature for heating should be balanced with the amount of Feldspar to enable eutectic formation without complete penetration. Too much Feldspar, that is above the amount previously indicated, would enable progressive reaction to penetrate farther into the shell mold where undesirable conditions can be developed since the Feldspar is capable of reaction with the metal while in the molten state. Further it can form products which do not have the desired heat-shock resistance and thus the formation of such products should be limited to outer portions of the shell mold. Thus it is desirable to limit the addition of Feldspar to dip coat compositions forming the outer coatings or the outer coating of the shell mold. While description has been made to the use of the outer coating as the eutectic coating containing the Feldspar, it will be apparent that the eutectic coating can constitute one of the intermediate dip coats, which may or may not be stuccoed, on the condition that the eutectic coat is spaced at least two coats and preferably five or more coats from the face of the shell mold.

Practice of the concept described by modification of the dip coat to embody Feldspar in an outer coating provides a shell mold having an inner face which is still highly refractory and incapable of reaction with the molten metal and an outer coat which functions as a lower maturing coat which is capable of automatically sealing up pores and cracks that may form while at the same time wetting the particles with the eutectic type of binder markedly to increase the strength and toughness of the shell mold while, at the same time, reducing its heating time and temperature to maturity.

By varying the composition of the eutectic coating, temperature for maturing can be varied from 1000-2300° F. Though not equivalent, use can be made of iron oxide, borax or stannous chloride and the like low temperature vitrifiable inorganic materials instead of Feldspar. The eutectic coat composition will generally be used at a lower viscosity than the conventional dip coats for stuccoing. In the composition described, the Feldspar acts differently than borax in that it is capable of greater stability in suspension without upsetting the balance as compared to borax.

In the firing operation to mature the ceramic materials and to effect removal of the wax patterns from the shell mold, it is desirable to avoid the use of temperatures much in excess of 2200° F. because otherwise the materials will tend to form a glassy phase which adversely affects the mold. The minimum temperature is that temperature sufficient to activate the binder. For borate, temperatures as low as 500° F. could be used but, in general, it is preferred to make use of a temperature in excess of 1600° F. because it is difficult to effect the

desired sequence in the elimination of the wax pattern and parts when firing at temperatures below 1600° F. Within the temperature range of 1600-2200° F. time is not an important factor. Very often 3 minutes is sufficient at these temperatures but it is preferred to heat for about 30 minutes. Heating for more than 30 minutes at the temperatures described is not harmful. Above 2200° F. the strength properties of the shell mold will be increased but reactions are possible which might cause excessive shrinkage in the shell mold.

In general, the thickness of the dip coats will increase from the inside out because of the increased porosity provided by the stucco. However, on the average, a shell formed of about five dip coats and an equal number of stucco coats will have a thickness of about ¼ inch and will be made up of about 60 percent by weight dip coat solids, 35 percent by weight coarse stucco of 14-28 mesh, about 2 percent by weight of 20 mesh stucco from the first stucco coat, about 3 percent by weight 54 mesh stucco from the second stucco coat, Feldspar will form about .5-1 percent by weight of the shell and it will be located almost exclusively in the outer layer or layers before firing.

After the eutectic coat, it is desirable to dry the mold for about 8-15 hours before firing. After firing, the shell mold may be processed by grinding down the lip to provide a flat surface for clamping to the top plate of the melting furnace to achieve a sealing relationship therebetween which enables the shell mold to be clamped to the furnace whereby the furnace is subsequently inverted for pouring. After firing, it is preferred to also provide an additional eutectic coat on the outer surface of the shell to provide increased amounts of vitrification or insipient fusion and to provide additional Feldspar for sealing the cracks and pores formed during the subsequent preheating operation and metal pouring operation. As previously pointed out, the shell mold formed in accordance with the practice of this invention bears sufficient strength to enable it to be clamped directly onto the furnace for metal pouring as distinguished from the necessity to invest the shell within a ceramic support as in previous investment casting processes. The shell mold can be critically inspected prior to preheating and subsequent to preheating and prior to clamping the shell onto the melting furnace to discard defective shell molds and thereby avoid the waste of time and material in pouring unsuitable and unacceptable castings. Preheating can be carried out in the usual preheating furnace to raise the temperature of the mold to a desired high temperature for metal casting thereby to insure complete flow of the metal into the innermost recesses of the mold with the result that acceptable castings of a uniform high quality can consistently be secured.

The cast metal shell can be removed from the furnace and set aside for cooling to solidify the metal but, as previously pointed out, castings having improved physical and mechanical properties and improved formation can be secured, when, in accordance with the practice of this invention, the poured shell mold is confined within a thermal insulating barrier during the cooling operation to solidify the metal or placed within a confined space subsequently filled with vermiculite or other particulate thermal insulating material. Instead, the poured molds can be allowed to solidify in a furnace heated to elevated temperature to slow the solidification or the metal can be poured into a mold while housed within the furnace in which it is preheated or in another furnace.

It will be apparent from the foregoing detailed description that considerable advantages are capable of being derived by a metal casting process embodying features of this invention:

(1) It is possible to reduce the firing operation from the 16 or more hours characteristic of conventional investment casting processes to as little as from 3-30 minutes.

(2) The materials employed in the preparation of the shell mold for casting can be reduced from a representative value of \$2.50 per cluster to as little as 90 cents for an equivalent cluster. The foregoing applies to the mold materials only since the investment can be completely eliminated.

(3) The increased strength and mass integrity of the shell mold formed in accordance with the practice of this invention permits the shell mold to be clamped directly to the furnace for pouring as distinguished from the necessity to invest the shell mold in conventional investment casting processes.

(4) The ability to clamp the shell mold directly to the furnace for pouring coupled with the high strength characteristics of the shell mold at the elevated temperature conditions existing permits the use of pressure in the metal casting process to achieve more rapid and complete filling of the mold as distinguished from the inability to make use of pressure in other shell molding processes.

(5) Because of the more refractory materials and their combination in a shell mold produced in accordance with the practice of this invention, it is possible to pour metal at higher temperatures which leads to the further possibility of pouring a greater variety of metals in the metal casting process. In addition, the ability to make use of a higher metal pouring temperature is directly instrumental in achieving more complete flow of the metal in the mold to achieve more uniform and better castings.

(6) Because of the good thermal characteristics of the materials making up the shell mold, a wider range of temperatures is possible to enable pouring of the metal into shell molds both hot or cold.

(7) The ability completely to inspect the shell mold in advance of metal pouring is instrumental in reducing the scrap loss of the metal casting process by comparison with prior investment casting processes wherein the mold is incapable of being inspected prior to metal pouring. Thus it is possible to eliminate defective molds before pouring metal castings therein to produce defective castings thereby greatly to increase the yield of acceptable products.

(8) By reason of the ability to clamp the shell mold to the furnace, considerable conservation in heat can be effected by comparison with the transfer process heretofore required in pouring the metal from the melting furnace into a ladle and conveying the ladle to the mold for pouring.

(9) It is possible also to melt the metal in the furnace under a protective atmosphere and to maintain the desired protective atmosphere during the pouring of the metal into the shell mold when clamped, as previously described, to the melting furnace. Such protective atmosphere cannot be maintained where the metal must be removed from the melting furnace for transfer by ladles to the mold for pouring.

It will be apparent from the foregoing that we have provided an improved method and materials for the production of metal castings. It will be understood that changes may be made in the details of materials, their formulations, their applications and in the operations without departing from the spirit of the invention, especially as defined in the following claims.

We claim:

1. In a metal casting process wherein a plurality of stucco and dip coats of finely divided ceramic material are built up onto the surface of a pattern of material which is disposable at elevated temperature and which is subsequently fired to dispose of the pattern and to mature the ceramic materials in the coating and wherein a metal in a molten state is poured into the matured mold to produce metal castings, the improvement which comprises incorporating a ceramic material having a lower maturing temperature than the other materials making up the plural coatings with the lower maturing

ceramic material in the outer portion of the composite coating whereby the lower maturing ceramic material in the outer portion of the coating reaches a state of incipient fusion during firing of the mold to an elevated temperature above the incipient fusion temperature of the lower maturing ceramic material prior to metal pouring to seal the cracks and pores formed in the mold to prevent the flow of molten material therethrough and to strengthen the mold to enable use without additional support during metal pouring.

2. The metal casting process as claimed in claim 1 in which the heat step for removal of the heat disposable patterns and maturing the mold is carried out by exposing the coated patterns to a temperature within the range of 1600-2200° F.

3. The metal casting process as claimed in claim 1 in which the ceramic material in the dip coats comprises a material having a high melting point range above 3000° F. and a low inversion factor to enable heating of the mold shell to higher temperatures in wax removal, preheating and pouring and to enable rapid temperature change to take place in the mold without excessive expansions and contractions.

4. The metal casting process as claimed in claim 2 in which the material is selected from the group consisting of zircon, alumina, titania, stabilized zircon, fused quartz, thoria, chromite, sillimanite, mullite, magnesia and vycor glass in a finely divided form.

5. The metal casting process as claimed in claim 1 in which the ceramic material of lower maturity is incorporated as a dip coat applied subsequent to at least three previous dip coats and before firing.

6. The process as claimed in claim 5 which includes the step of air drying the structure subsequent to the application of the coating of low maturing material and before heat treatment to mature the mold.

7. The method as claimed in claim 5 which includes the additional step of applying a second coat of the low maturity material subsequent to the firing for maturity and which includes the step of preheating the mold in advance of the metal pouring step to cause incipient fusion of the applied low maturity material.

8. The method as claimed in claim 5 in which the low maturing material comprises Feldspar in a finely divided form.

9. The method as claimed in claim 8 in which the mold shell is preheated to a temperature within the range of 1600-2200° F. prior to metal pouring.

10. The method as claimed in claim 1 in which the matured shell mold is clamped directly onto an invertible metal melting furnace for pouring the metal into a shell mold.

11. The method as claimed in claim 10 which makes use of super-atmospheric pressure in pouring the metal in the clamped mold.

12. The method as claimed in claim 10 which makes use of an atmosphere inert to the molten metal during melting of the metal and pouring of the molten metal into the shell mold.

13. The method as claimed in claim 1 which includes the step of controlling the cooling rate to slow the solidification of the metal.

14. The method as claimed in claim 13 in which the step of slowing the solidification comprises surrounding the mold with thermal insulating material in particulate form.

15. The method as claimed in claim 13 in which the step of slowing the solidification of the metal comprises housing the mold within a thermally insulated space immediately after pouring.

16. A shell mold produced by the method of claim 1.

17. A shell mold produced by the method of claim 8.

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