

1

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PROCESS OF MAKING REFRACTORY SHELL FOR CASTING METAL

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No Drawing. Filed Apr. 7, 1958, Ser. No. 726,658

7 Claims. (Cl. 22—196)

This invention relates to the precision casting of metals by the so-called "lost wax" and like processes and more particularly to improved ceramic shell type moulds and methods of fabricating and using same.

During recent years much work has been done to improve what is commonly known as the "lost wax" process in terms of material, cost, labor and time. The use of shell-type moulds in the "lost wax" process, in particular, has many advantages over solid mould techniques. It permits orientation of the expendable patterns in a manner conducive to sound casting in that the moulder is not restricted to standard sizes of flasks or containers. Also, permeability is such that pressure casting by vacuum or centrifugal means is no longer necessary in obtaining a proper fill-out of the mould cavity. The shell weight is far less, from a handling and cost standpoint per pound of metal poured. The reduced thermal capacity of the shell promotes progressive solidification and the rate of solidification can be externally controlled. A shell, especially one built up by successive dips, provides a multi-layer ceramic back-up of consistent permeability and thickness not possible by solid mould techniques.

In spite of these advantages, however, the presently known multi-layer shell techniques have several disadvantages. The required storage space is considerable, owing to the fact that in most processes each layer of the shell must be dried before the following layer can be applied. This involves much handling and a resulting high cost. The drying of each layer has a further disadvantage in that the slurry will re-saturate a previously-dried layer which will have to be re-dried beneath the freshly-applied layer. This leads to building a shell which will have a reduced permeability, and may require centrifugal or pressure casting techniques in order to obtain proper fillout of the cavity.

Another serious problem currently experienced is that of removing the expendable pattern. This is conventionally accomplished by utilizing a low heat for a considerable period of time to avoid breakage of the fragile shells, or the use of hot solvent vapours which dissolve the wax from the shell cavity. Both of these procedures, however, are time-consuming and costly and neither method makes possible the use of patterns made of organic plastic materials other than wax, as is desirable in high volume production work as a substitute for the conventional wax.

Furthermore, after pattern elimination, the shells fabricated by heretofore-known processes, because of their fragile nature must usually be invested in a loose refractory material, which is in turn surrounded by a heat-resistant container and the entire assembly must then be slowly brought up to temperature over a period of several hours for necessary shell curing prior to raising the temperature sufficiently for casting. This latter step, particularly the curing portion thereof, adds considerably to the processing time and cost since the resulting assembly makes a very bulky and unmanageable mould to handle, particularly when heated to high temperatures.

2

In an attempt to solve some of the above-mentioned problems U.S. Patents 2,806,269 and 2,806,270 suggest in the preparation of ceramic shells, two refractory slurries, one acidic and one alkaline. In this process, a shell is described as being built up by repeatedly dipping the sprue in one slurry, stuccoing with a coarse refractory and then dipping in the second slurry. The pH of each dip coat layer is alternately upset by dipping in the following slurry, thus causing a series of gelled shell layers to be formed on the sprue. This procedure presents several problems from a production standpoint. For example, progressive contamination of one slurry with the other due to the alternate dipping operations, tends to upset the stability of one or both slurries, and results in gelation of the slurry bath itself. Also, since the preparation of a high silica concentration with water-based silicates on the acid side causes instability, shell strength can be achieved only by increasing the silica concentration in the alkali bath, but this endangers the rigidity of the shell at elevated temperatures, and produces a shell which becomes semi-plastic and may distort at such temperatures. As a result, in any but the smallest sizes, such a shell would have to be supported for casting by a loose refractory as above described. Furthermore, the problems of removing the wax pattern followed by shell curing at a low temperature are not solved by the procedure described in said patents, and so remains a slow and costly step. Furthermore, shell strength, particularly with the technique utilizing two refractory baths, is unsatisfactory, so that a long curing cycle and support during casting is necessary, and this, although not concerned with the process of shell fabrication itself, increases costs of the overall operation.

Until the present invention, then, there has been no precision casting technique wherein ceramic shell moulds may be economically fabricated continuously at a high rate of speed by automatic machinery, both because of the long drying time necessary for shell fabrication and because of the long time necessary for removal of the pattern and curing of the shell. The problems of time for multi-layer shell fabrication have been partially solved by utilizing two refractory baths, but gelation because of the inevitable mixing has caused difficulties with this technique. The present invention has, as a principal object, the fabrication of a multi-layer ceramic shell mould from organic material patterns by continuous, automatic procedures, through substantial elimination of drying time during fabrication of the layers of the shell itself and by the elimination of the requirements of careful pattern removal and shell curing. This latter feature makes possible simultaneous pattern removal and shell curing by flash heating at a temperature which may be equivalent to or even higher than casting temperatures so that the casting step may follow immediately upon the conclusion of the shell fabrication steps of the process. Furthermore, shell strength is so much improved by the present invention that casting may be carried out in unsupported shells of sufficient porosity so that centrifugal or other pressure-assisted techniques are unnecessary.

The above objects and features have been accomplished primarily by the utilization of novel gelation or combined pH upsetting and low temperature binding materials utilized in a dry state, that is, preferably an air or gas-applied alkaline low-temperature binder powder as by dusting, between dippings in a liquid slurry for building up the multilayer shell of the invention. More specifically, the multilayer shell building operation of the invention involves for each layer three basic procedures which combine to form a cycle. First, the precoated sprue is dipped in an acidic slurry having a volatile medium containing refractory binders and refractory powders of varying mesh

3

sizes. The sprue is thus coated with a heavy layer of slurry. After draining off excess slurry the sprue is submitted to the second operation which involves stuccoing the wet coat with a coarse refractory grit. This provides a mechanical keying for the following shell layer, a practice well known in the art. The final operation follows immediately after stuccoing and involves dusting the sprue with a dry alkaline low-temperature binder in powder form so that particles of such binder adhere to the slurry between the coarse grit stucco particles. In this manner, two results are obtained as a result of the one operation; first, the alkaline nature of the powder upsets the pH of the slurry which rapidly gels and becomes set; and second, a low-temperature binder has been incorporated in the shell structure. After gelation has taken place, which occurs within a few minutes, surplus powder is blown from the sprue and the cycle of operations is repeated to deposit another layer and so on until a shell of adequate strength has been formed. It will be appreciated that the alkaline binder may be incorporated in the stucco rather than being applied as a separate step, but cannot be as easily controlled owing to the fact that the fine binder powder will adhere to the slurry coat more readily than the coarse stucco. Such binders cannot, however, be incorporated in the acidic slurry because it would cause rapid gelation thereof.

Shells relying upon high temperature binders only tend to be fragile at the lower temperatures and hence require careful pattern removal by the use of hot water, solvent vapours, etc. Also such shells, when removed from the furnace, encounter a temperature gradient to room temperature sufficient to break down the rigid high temperature bond due to the varied and rapid contractions taking place on the outer layers of the shell; the shell immediately becomes fragile again and will frequently crack due to this factor alone. Hence, with such shells, it would be necessary to surround the shell prior to burn-out with a loose refractory which acts as a physical support to the shell walls and to protect the shell from this high thermal gradient.

The introduction of the low temperature binder in accordance with this invention, overcomes these two disadvantages and permits rapid high temperature elimination of the pattern and provides sufficient strength to withstand molten metal in the casting operation without additional support. During the early stages of pattern elimination at high temperatures, several layers of the low temperature binder will be in a very tough and tenacious condition, thus contributing considerably to the strength of the shell. When the pattern is removed, the whole shell rises to a uniform temperature, at which time the low temperature binder becomes ineffective and the rigidity of the shell is maintained by the high temperature binder alone. After firing, the shell is removed from the furnace and immediate chilling of the outer layers takes place. The low temperature binder again becomes effective in resisting the metallostatic pressures involved in the casting operation and protects the shell from the effects of thermal shock on removal from the furnace. The effect of combining these different binders, preferably in distinct and separate layers as is preferred, results in increased shell rigidity and strength at all temperatures.

In the choice of low temperature binders, I prefer to use substances having an alkali metal salt base and which have melting points between 600 and 1000° C. Such salts include sodium and potassium meta-borates and tetra-borates and penta-borates. The phosphates and fluorides of sodium and potassium may also be used.

It should be understood that prior to carrying out the steps of the invention as above described, suitable patterns are first precoated and to accomplish this wax or plastic patterns are mounted on a sprue in a similar manner to that used in the conventional processes. There is, however, more opportunity to affix the patterns to promote good feeding characteristics owing to the lack of invest-

4

ment volume and can size limitations. The patterns and sprue are then precoated by dipping in a refractory slurry, drained, and then stuccoed with a sharp angular sand. The first coat determines the standard of finish which will eventually be transferred to the casting. Most known precoats will prove satisfactory for this purpose, although because of the high speed in which the shell is fabricated according to the present invention, a binder using a large proportion of volatile solvent is preferred.

For the purpose of explaining further objects and features of the invention, reference is now made to certain preferred embodiments thereof.

In a preferred embodiment of the invention, the following precoat formulation has proved to give excellent surface finish reproduction.

Mix A:	Cc.
Methyl alcohol	1900
Methyl ethyl ketone	100
Stock solution:	
Ethyl silicate 40	2400
Mix A	540
Water	60

The above water addition contains 8% hydrochloric acid. This binder is mixed according to known procedures and may be used on the day following preparation.

Precoat slurry:	
Stock solution	cc-- 2625-2700
Methyl alcohol	cc-- 1312
Silica flour (#200)	grms-- 10,020
Bentonite	grms-- 94
Wetting agent	cc-- 4

The wax sprue is dipped into the above slurry, and after careful draining the coat is stuccoed with a crushed silica sand. The mesh sizing of this sand will depend on the size and intricacy of the casting being made. The stucco sand is applied to provide a mechanical keying to the following shell coat, such procedure being common practice in the art.

The precoating operation may be followed immediately by the shell building operation, by accelerating the gelation of the coating by methods to be described later in the shell building operation. However, the above-mentioned precoat formulation is suitable for either accelerated gelation or prolonged drying, so that a production line may be arrested at this point if desired.

According to the present invention, a variety of specific embodiments of the fabrication of the multi-layer shell utilizing a gas-carried alkaline low-temperature binder material for gelation between dippings may be utilized. Thus, in one embodiment of the invention, a hydrolyzed solution of ethyl silicate is prepared in a manner well known to those skilled in the art. I prefer to use a solution containing a substantial proportion of a volatile medium having a silica concentration in the order of 25%; however, weaker solutions will be found to be satisfactory for smaller shells.

	Percent
Ethyl silicate	58.9
Methyl alcohol	33.9
Water	7.2
Hydrochloric acid	.1

A refractory slurry is prepared by mixing with the binder a refractory powder. There are many combinations of flours and sands which will provide a satisfactory slurry mix. The aggregate, however, should be such that a high solid liquid ratio be obtained together with adequate fluidity. In a preferred embodiment of the invention, the following is recommended:

	Percent by wt.
Silica flour, 200 mesh	50
Silica sand, 60 mesh	50

A typical analysis of these materials is as follows:

Silica flour -----	98% through 200 mesh.	
Silica sand:		Percent
On 40 mesh -----		4.1
50 -----		19.0
70 -----		32.4
100 -----		32.7
140 -----		9.5
200 -----		1.7
Pan -----		.6

The liquid solid ratio required for the acidic slurry will depend on the binder concentration and the specific surface area of the refractory materials chosen. The fluidity range should be in the order of 700-800 Redwood seconds. Using materials described above, it will be found that the addition of 53 lbs. of powder to 10,000 cc. of hydrolyzed binder will result in an activated fluidity in the above range. The slurry is kept under continued agitation while shell building is in progress, so that complete mixing is maintained.

The precoated sprue is now immersed in this slurry and after draining is sprinkled or stuccoed with a coarse refractory grit. The mesh sizing of this grit will depend principally on the dimensions of cored passages in the patterns being coated. As a general rule at least one shell layer must be applied to all cored areas before the core becomes blocked by shell material. The stucco refractory must be free from dust. I prefer to use a calcined aluminum silicate having a sieve analysis approximating to

Pass 16 mesh on 20 -----	20% cum.
Pass 16 mesh on 30 -----	65%.
Pass 16 mesh on 40 -----	80%.
Pass 16 mesh on 50 -----	95% min.

After the sprue has been completely coated with stucco, it is dusted with a dry-powdered alkali binder from the groups referred to above. I prefer to use sodium tetraborate which is more commonly known as borax. The sprue is then allowed to dry for two or three minutes until gelation has taken place. Excess binder powder is blown from the surface of the shell and the cycle of operations is repeated until a shell of adequate strength has been applied. The number of shell layers will depend on the shape and size of the sprue; however, it will be found that between five and seven layers will prove adequate for most purposes. The precoat layer is similarly treated for accelerated gelation. The resulting shell thus essentially comprises alternating layers of refractory material containing ethyl silicate as a silica binder and refractory material containing borax as a low temperature binder.

Another embodiment of the invention relates to increasing the shell strength beyond that described above. The same hydrolyzed binder may be used, but I incorporate in the slurry a second high temperature binder. This binder must, of necessity, be acidic or be substantially insoluble in alcohol so that the ethyl silicate slurry will remain stable. I have found that magnesium ammonium phosphate may be effectively used for this purpose:

Hydrolyzed binder 25% SiO ₂ -----	cc.	10,000
Silica flour #200 -----	lbs.	21
Silica sand #60 -----	lbs.	25
Magnesium ammonium phosphate -----	lbs.	4

A fluidity of between 700 and 800 Redwood seconds should be maintained. The precoated sprue is dipped in this slurry as described earlier. In this manner a shell is prepared containing three ceramic binders, including an additional high temperature binder in the refractory layer containing ethyl silicate. Such shells will withstand greater stresses than those prepared with only two binders.

In the event of exceptional strength being required,

either of the above shells may be further strengthened by dipping the dried sprue and the shell formed thereon in a clear solution of hydrolyzed ethyl silicate binder.

With regard to suitable refractory flours and sands for use in building the shells of this invention, I have referred only to cheaper materials such as silica and aluminum silicate. It should be appreciated that many different refractory materials may be substituted to give the same and even improved results, the limitations being only the refractoriness and purity which the user requires for his particular purpose.

As is preferred with the present invention, pattern elimination and the firing of the shell take place at the same time in one operation. Contrary to standard procedures of low temperature pattern elimination, ceramic shells fabricated by the techniques described in this application can be subjected to high temperature shock treatment even up to between 1500 to 2000° F. without damage to the shell, since heat is transferred very rapidly to all sections of the mould in the same period of time. The shell accordingly expands generally uniformly and heat is conducted through the shell at a considerably greater rate than through the wax or plastic patterns which are themselves comparatively good thermal insulators. The surfaces of the patterns are hence almost simultaneously melted and begin to flow out through the sprue mouth. As a result, the pattern is removed before stresses due to thermal expansion of the patterns can become effective in causing fracture of the shell. The shell is sufficiently permeable to relieve stresses which might otherwise be caused by the ignited gases resulting from flash firing the patterns.

Owing to the low thermal capacity of the shell, the burn-out cycle is generally less than one-half hour and may be reduced to as little as fifteen minutes as compared with 8 to 16 hours required for the denser and more massive solid mould and the invested shell type mould as a result of the superior characteristics of the shells of the invention which permit immediate application to the shell of temperatures over 1200° F. Accordingly, the furnace temperature should be at least as high as 1200° F. and preferably of the order of 1500-2000° F., commonly about 1800° F., to insure a complete and satisfactory burn-out of the pattern from the shell and simultaneous shell curing by firing. After burn-out, the shells may be cooled to the desired casting temperature. The casting operation is simplified in that vacuum, centrifugal or pressure casting techniques are not necessary; cooling can be controlled and localized to promote progressive solidification if desired.

After cooling of the cast metal, the shells are vibrated away from the castings and normal finishing procedures assumed.

Numerous modifications of the formulae and procedures disclosed are contemplated as falling within the scope of the invention as defined by the following claims.

I claim:

1. A process for making a refractory shell into which molten metal may be cast which involves forming a multi-layer shell around an expendable pattern, comprising the steps of coating said pattern at least twice with a slurry containing a silica binder and refractory powders, applying a stucco of coarse refractory material to the slurry deposited on said pattern after each slurry coating step and applying to each stucco coat a dry alkaline binder material and thereafter removing said pattern from said shell and firing said shell.

2. A process for making a refractory shell into which molten metal may be cast which involves forming a multi-layer shell around an expendable pattern, comprising the steps of coating said pattern with a slurry containing a silica binder and refractory powders, applying over said wet slurry coat a dry stucco of coarse refractory material and a powdered dry alkaline binder

material, applying another coating of said slurry over said stucco and said binder material, then applying additional said dry stucco and said dry alkaline binder material over said last-named slurry coating, and thereafter removing said pattern from said shell and firing said shell.

3. The process claimed in claim 2 wherein the dry alkaline binder, when applied, is incorporated in the said dry refractory stucco.

4. The process claimed in claim 2 in which said binder material is an alkaline metal salt having a melting point between 600 and 1000° C.

5. The process claimed in claim 2 wherein the binder material is sodium meta-borate.

6. The process claimed in claim 2 in which the silica binder is ethyl silicate.

7. The process as claimed in claim 2 in which the shell with said pattern is heated to about 1800° F.

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