Key Factors for Shell Making Success

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There are many aspects to ensuring success in the shell room: Materials, Equipment, Procedures, Training, and Management. One of the most important aspects is process control. I think the 80/20 rule holds for success in the shell area. Twenty percent of success is determined by Materials, Equipment, and Procedures and Eighty percent of success comes from being consistent. While an emphasis must be placed on process control, there are several key process items that are worth reviewing for possible adjustment of the shell process.

Wax Cleaning: The wax tree needs to be cleaned to remove oils, dirt and wax chips. The current norm is to use some type of Citrus based cleaner. Citrus cleaners have replaced chlorinated hydrocarbon solvents due to environmental issues. Usually these cleaning and rinse tanks are not maintained well in terms of cleanliness or concentration of the active ingredient, d-limonene. D-limonene is also a VOC (volatile organic compound) that is potentially subject to State and Federal regulations. At a minimum, keeping the tanks clean by continuous filtering and flushing is good practice.

First Dip: The most common prime slurry consists of zircon flour with 10 - 20% fused silica flour and either large or small particle size colloidal silica and some type of polymer. The amount of fused silica used ranges from 0 to over 50%. At the higher levels of fused silica, the zircon is only present to improve the draining characteristics of the fused silica slurry. It is not present is sufficient quantity to have a significant effect on the casting. The main functions of prime slurry are:

1. Compatibility with the metals to be cast. Most alloys are compatible with zircon and alumina. Some are not compatible with silica.

2. Slurry draining characteristics should be able to produce a smooth uniform coating on the wax. Edges of patterns should be coated and wet enough to accept stucco. A non-uniform prime coating can result in casting defects, notably inclusions.

3. Prime slurry needs to adhere to the wax and hold prime stucco tightly.

4. The prime slurry should have usable life that is suitable for the size of tank and amount of product being dipped. Slurry life is a function of all the components in the slurry: binder, flour, polymer, and other additives. As an example, zircon flour generally drives the slurry pH down due to naturally occurring soluble contaminants. This can cause partial gelling of the binder leading to quality issues on castings and the entire slurry may need to be replaced. Work closely with your supplier to select appropriate binders, flours, and additives for your application.

5. Green Permeability, especially of the early dips, is necessary for liquid wax to be able to soak into the shell to relieve increasing wax pressure on the shell during dewax. If green permeability is low, dewax cracking is very likely. See photo below of green permeability being run in our lab. Note that too much polymer in the slurry may decrease green permeability. See **Figure 1**.

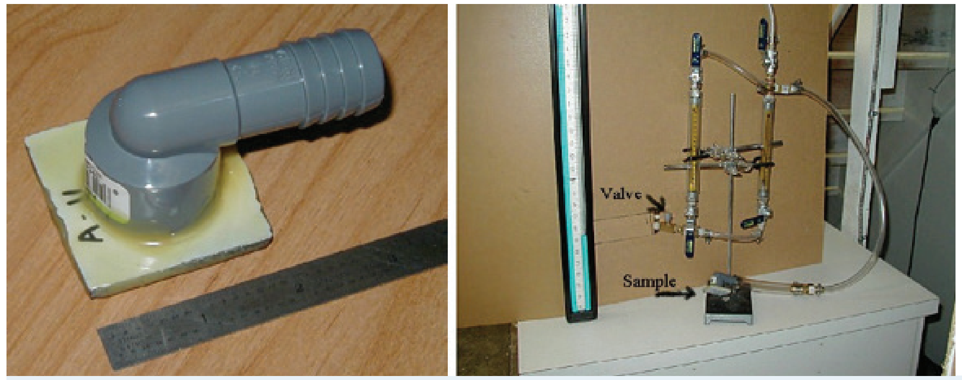

Figure 1: Green Permeability Measurement

6. When dry, the prime slurry must hold the primary stucco tightly. Loose stucco on prime dip needs to be cleaned off. Loose stucco, especially in corners, can result in shell particles getting into the castings causing scrap and rework for inclusions. Polymer helps to hold stucco tightly.

Transition Dips: Their function is to gradually fill the detail of the wax pattern after first dip and before the backup layers. These slurries are usually thin compared to the first dip slurry. Important characteristics of good transition slurries are:

1. Ability to easily wet into the dried prime layer without excessive bubbles prior to stucco application.

2. High green permeability as mentioned for prime dip.

3. Stucco held tightly when dry. No loose sand.

4. Layers bonded well before and after dewax. No delamination between layers during preheat and casting.

Transition dips can be accomplished in one of two ways: Either by using thin slurry or by using a pre-wet and thicker slurry. My preference is to start with the thin slurry and try to make that work before using a pre-wet. Pre-wets are subject to their own process control issues.

For successful transition dip applications, the stucco size must be appropriate for the viscosity of the slurry. Generally, lower viscosity slurries need finer stucco in order to have adequate slurry to hold the stucco tightly. The stucco size must also match the detail of the patterns to be dipped. Suppliers can recommend various options.

Backup Dips: When sufficient detail on the pattern has been filled using transition dips, back up layers are used to build bulk for shell strength. The amount of strength should be sufficient to handle the shells without breaking pieces off the mold. In addition, sufficient strength is needed to dewax the mold without cracking. Usually, this is enough strength to hold metal at casting. The backup slurry should be able to cover edges of the mold as well as it covers flat areas. Sufficient shell must be applied to ensure edges do not crack at dewax. Edges are the weak areas. Slurry that leaves material on the flat areas while draining off the edges will require more dip applications to build edges thick enough. Fiber enhanced slurries do a better job of covering edges and thus require fewer dips. See Figure 2 which shows the shell thickness for traditional and fiber enhanced slurries with equal number of dips.

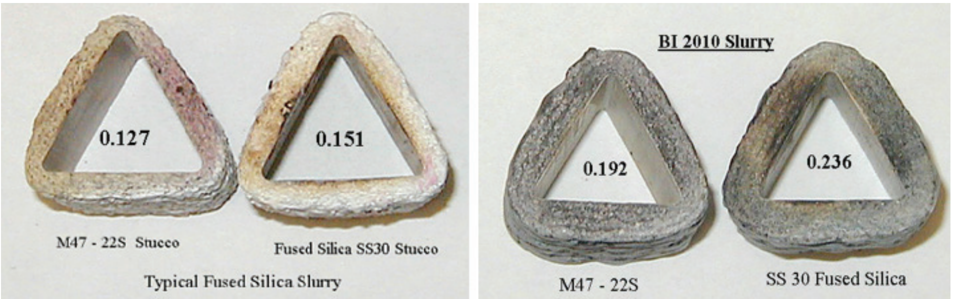

Figure 2: Shell thickness and uniformity Improvement using Organic Fiber enhanced slurries. Equal number of dips on all samples.

Backup Stucco is the largest stucco used and the backup slurry viscosity can be increased to match stucco size allowing for fewer dip applications. This method again allows for few dip applications. Common stucco sizes for backup dips are from 20 to 40 mesh average size.

Stucco application is also important. Rainfall hoods are generally preferred for prime and intermediate stucco applications while backup stucco is often done with a fluidized bed of sand. This is true for hand dip or small robot tanks, but larger sized fluid beds can be difficult to maintain properly and thus rain fall hoods are often used. One caution is that rain fall hoods and fluid beds do not cover shell edges the same. Rainfall hoods tend to build thinner shell on the edges. Fiber slurries can help with this problem to maintain edge thickness.

Seal Dip: The function of the seal dip is to bond loose grains of sand. Additionally, the smoother outer surface of the shell makes it easier to apply insulation and it is easier on the hands of the operators.

Drying: When water evaporates from colloidal silica binders, there is a chilling effect on the wax. The wax shrinks as a result of this cooling. When the water is substantially removed, the silica gains strength. The wax then begins to warm and expand. This expansion imparts a tensile stress on the thin layer of dry ceramic, which can cause a crack in the ceramic layer. This is true even if the room temperature is held absolutely constant. Variation in room temperature can make the wax shrinkage and expansion problem worse. Polymer in the prime can help accommodate this wax expansion and stress on the thin shell layers.

In order to minimize the wax shrinkage, the conventional technique is to use little air flow and high humidity until most of the water has evaporated. This technique extends the time required for drying and spreads the cooling over a longer period of time resulting in less of a wax temperature depression. There are other ways to accomplish this low impact drying, but in shorter time. An example is the MK Technology dryer that uses Infrared lights to offset the cooling of the wax that would occur with the high air flow and low humidity used to make the shell dry quickly. This machine was presented at the ICI Equipment show in 2011 in Cincinnati.

Drying times for layers are generally longer as more dips are applied and the shell thickness is greater. Final dry is generally done by allowing shells to dry overnight for 1 or 2 shifts. Usually, this is done as a matter of convenience rather than for a process requirement. Figure 3 is an example of how drying affects shell strength. Inter-dip dry times were 3, 5, 8 hours and final dry was 6, and 12 hours.

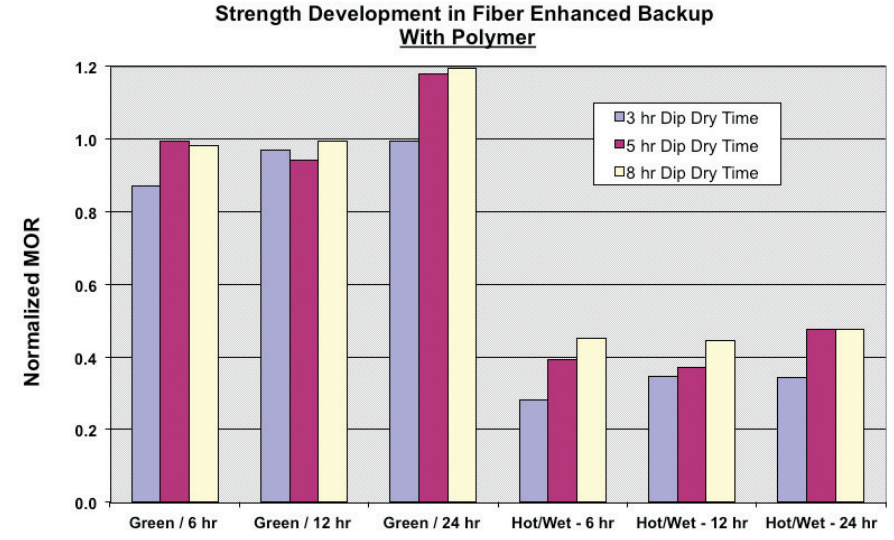

Figure 3: Strength Development with various interdip and final dry times

In summary, be consistent and discuss your particular situation with your supplier to solve problems or improve yields.