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## Casting Metal Directly onto Stones

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Setting stones into a wax model and casting metal directly around them can attain significant labor cost savings. This procedure requires several carefully monitored steps to avoid damage to the stones, including good form-filling at modified casting temperatures, minimal thermal shock, and controlled metal flow to achieve good results. The caster must understand the scientific principles involved in this procedure; otherwise it should not be attempted.

### Stone Selection

Diamond, ruby, sapphire, garnet, and most synthetic gems can be directly cast in place. Larger, more expensive stones should not be attempted because the risk of damage to the stone, outweighs the cost savings. Stones in the quartz family, organics such as pearls, highly included or fractured stones, and stones known to be heat-sensitive should not be cast in place. Gemstones that have been found to be unsuitable include amethyst, emerald, lapis, pearl, opal, peridot, topaz, tourmaline, and turquoise. Some of these stones—such as aquamarine, tourmaline and even emerald—have been successfully cast in place, but they are not recommended for high production runs due to wide stone variations. This list of unsuitable stones is not guaranteed to be all-inclusive, nor does it guarantee the suitability of others. The jewelry manufacturer is cautioned to make comprehensive tests to determine stone suitability using this procedure before going into production. The degree of success can be greatly affected by model design as this is a very important part of the equation when casting stones in place.

### Model-Making

Modify the metal model once, not each wax! Any change to the wax is time-consuming and defeats the overall purpose of this labor-saving process. There are a number of considerations to take into account when producing the models for casting stones in place. Stone shape and model designs are some of the most important considerations with regard to success of stone-in-place casting. Stones with sharp angles require special model design so they are not broken when the metal cools. Special care should be taken with stones with points (such as marquise, baguette, princess cut, etc.) to avoid damage caused by metal shrink, or uneven thermal expansion rates. Spacing of the stones to allow for metal shrinkage must be carefully planned. Stone girdles must not touch in the wax. As the metal cools it contracts and reduces the space between the stones. Any stones that are touching may crack because of the pressure of the cooling metal.

Seats (grooves) for the girdles of the stones must be cut into the model so that when the injected wax is taken from the mold, the stones can be held firmly in place by the tension of the wax. The stone's exposure to the investment top and bottom is absolutely required. This support needs to be heavy enough to hold the stone firmly while the metal is filling around it. This support is gained by opening up the holes under the stones large enough to give the proper support while keeping the walls thick enough to allow metal to flow. If not, the thin supporting structures under the stone may fail and become investment inclusions on the surface of the casting. Another defect that this situation causes is that because the stones are no longer supported properly by the investment, the stones may drop causing metal to fill in over the top of the



stones. If metal does not go over the stones then the other issue is that metal can fill in behind the stones causing them to appear dark.

You must always keep the surface area to volume ratio of the metal in mind when making any model, especially a stone-in-wax model. A stone-in-wax model cannot be considered in the same way as a regular production model that is not being cast with stones. Stone-in-wax models should be configured differently

and with more consideration to a very fast complete fill than is necessary with regular models. This does not always mean heavier models but it sometimes does. Good stone-in-wax models make ultimate use of the properties of geometry and cooling. For example, the use of a domed shank instead of a flat shank of the same volume aids in filling because of the surface-to-volume ratio of the two different geometries. Using rounded shapes instead of thin flat shapes for the models can often obtain similar looks with far superior casting results. The stones themselves are heat sinks—especially diamonds. The stones absorb a great deal of heat during the casting process and can cause the pieces to not fill completely in a poorly designed model. Flask temperatures are especially critical in stone-in-wax casting to ensure stone safety. Don't exceed the maximum flask temperatures for the stones you are casting around. Flask temperatures are also the most critical aspect of sound castings, stones or no stones. Increasing flask temperatures to ensure complete part fill can cause more damage to the casting surface than increasing metal temperatures, especially in parts with heavy cross sections. You may get the parts to fill, but the timespent cleaning up the porous castings can quickly eat up your profit margin. Non-filling and recasting will certainly eat up your profit margin, so it is best to carefully design your stone-in-wax models and plan for their differences from the start.

Design your models so that a minimum amount of stone is in contact with the metal while still being securely held. It is ideal for the stone to snap into place without the need for heating the stones with a heated tool. The purpose of using heat at all is to eliminate any space between the stone girdle and the securing structure (prongs, channel). Any spaces left in these locations will likely cause investment inclusions during metal injection, as thin slivers of investment will fill any remaining gaps and can break off and float in the metal stream. Since the density of the investment is much lighter than the metal, it is most likely that the investment will be pushed to the surface and form an inclusion. After you have

cast and cleaned off the investment from your castings these inclusions are often identified in your quality inspection as porosity (or simply holes) because the investment is simply no longer there for them to see.

Another very important issue with regard to the use of heat when setting stones in wax is the proper spacing between the securing structures (prongs, channels), the height of the prongs, and the quality of the channels. When the spacing is too small and the stones will not snap into the seat, a setter will often use a heated tool to force the stone into the seat. This will certainly get the stone down into the seat, but it will likely melt a lot of wax on the way down. This melted wax not only reduces the amount of support the stone gets from the investment under the stone, it often completely covers the back of the stone with wax. As you know, all that is wax becomes metal during casting—and either the stone will drop into the cavity left by the wax elimination and be covered by metal or the back will be closed and the stone will look dark. And if the investment column that was under the stone no longer has the strength of the connection between itself, the stone, and the investment above, this now-freestanding column of hot, weak ceramic will break away during casting to form a surface investment inclusion. In stone-in-wax casting, prongs need to be the minimum length and precisely pre-cut to reduce gaps between wax and stone so that the wax will maintain adequate tension on the stones during investing. Prongs that are too long will make it difficult to get stones into place, and will require more finishing labor steps later in the production process. Long prongs also increase the likelihood of porosity on the prong, subsequently causing brittle prongs. We have already discussed that stones are heat sinks: the seat that is cut into a prong creates a thin area between two thick areas of a casting. This, combined with the heat sink properties of the stones, creates a situation where the tip of the prong is cooling at a slightly slower rate of speed than the area before it. This condition causes the prong metal to be weaker at the seat and above as compared to the metal below. Using a minimum-length prong gets the rate of cooling closer together with the seat and helps relieve some of this stress and porosity. Shorter prongs require less finishing and are less likely to get snagged and cause a break by the customer later on. The shape of the prong is also important to ensuring successful fill rates. Different designs require different considerations. Prongs do not always need to be round or rectangular even though they most often are. Geometry and model configuration must be considered very carefully when making those types of decisions. Channels and bezels must have enough material at the apex of the stone seat to allow metal to fill those areas during

casting. Besides using gravers and freehand cutting with burs, there are tools such as the AllSet™ that attach to a No. 30® handpiece that greatly enhance accuracy when cutting seats for stone-in-wax casting. Using this tool you can set the depth of the cut from the top of the channel or bezel as well as the depth of the seat itself. Some model makers feel that using such a tool is insulting to them as craftspeople—sometimes ignorance is bliss and sometimes it's just plain ignorance. Channel rails should be planned and designed at an angle to the outside of the channel. In case of a cracked or loose stone, this configuration offers the opportunity to replace or tighten stones so that the final channel rail shape can be flat and even, repaired or not.

Models must be designed so that they allow for quick, even heat diffusion from the metal, through the stone, and into the investment. Some larger stones can crack because the girdle of the stone is heated more quickly than the center portion of the stone. This is especially true with CZs. The difference in the rate of thermal expansion causes stress in the stone's crystal structure and fractures can take place. Minimum metal contact and maximum security should be the goal of the model maker when executing a design.

## Wax Memory

Injection wax with excellent memory should be used for stone-in-place casting. The wax patterns must deform when the stone is set and return to its original shape without breaking or cracking. Most waxes can be used right after they are freshly shot. Only a select few that are designed for this purpose maintain these properties for any length of time. In high-production situations, waxes are often shot and stored during slow periods and brought out during production peaks to smooth the workflow. I recommend using wax with these plastic properties of excellent memory. The wax you choose also needs to be of a color that is easy to read. What this means is that certain darker colors make it easier to see wax defects that may later result in a scrap casting. When casting metal around stones it becomes exponentially important not to have a scrap casting. Check with your wax injection personnel for their color preference for readability. Many wax manufacturers have waxes with the same properties in different colors just for this reason. If the stones tend to vary in depth and thickness, gaps between stones and prongs can occur and will fill with investment. These thin, sharp pieces of investment can break off during casting and become a surface inclusion somewhere in the casting. Because of this I do recommend very lightly seating the stones with a heated tool.

## Sprue and Gate System Design

I call the feeding structure that's attached to the part I want to end up with and the center metal conduit structure a gate. I call the center metal conduit structure between the gate and button the sprue. I do so in honor of a cranky ol' cuss that has been in the jewelry industry for a long time (and whom I admire); Albert M. Shaler. In the jewelry industry these names are not always used in this precise manner, but he insists on these designations—and who am I to argue with a cranky (but wise) ol' cuss?

Generally the gating to the pattern must be into the heaviest part of the model to help provide complete filling at the lowest temperatures. There are some rare exceptions but for this discussion it is not relevant. The sprue/gate system is the conduit for liquid metal to enter and fill the pattern and deserves a great deal of consideration. Properly designed, a good sprue system will provide a fast, directional fill with progressive solidification of the metal. The pattern or model itself should absolutely be considered as a part of the gating system. Therefore it is essential to decide where and how the gate is to be connected to the model before the first piece of wax is carved, or metal shaped.

Under ideal conditions and in simple terms on a typical woman's ring for instance, the prongs would cool first; then in progression the shoulders, the shank, the gate, the main sprue and finally the metal reservoir button. Since liquid metal shrinks when it solidifies, the ring must be fed liquid metal during solidification to prevent shrinkage porosity in the ring. The sprue/gate system should be designed to work with nature and allow progressive solidification by becoming progressively larger as it goes to the sprue button. This is an important element of any good casting and extremely important when casting with stones in place because the stones act as heat sinks.

In stone-in-wax casting the placement of the gate in relation to the setting type and shape is more critical than most people think. Forcing the molten metal to make sharp turns that cause turbulence in the metal stream and then expecting it to fill around the stones completely is just not possible. Attaching the gate in such a location as to cause uneven heat dispersion or shock to the stones can cause stones to break that otherwise would not have.

Gate shape is also critical in a complete fill, as well as in defectfree casting. Square gates should be avoided at all







cost. Gates with sharp angles or turns are not recommended. Long, thin wires as gates may help in wax injection to some small degree, but can often cause more harm than good in casting because they then become additional heat sinks. While there has been a huge amount of discussion over the years between me and my colleagues about the perfect gate shape, I can safely say that there is no one perfect shape for all situations.

## Building the Wax Tree

Use a main sprue of 3/8" (10 mm) diameter and leave approximately 1" (25 mm) of unused sprue from button to first branch (gate). Attach wax patterns with about an 80° angle to the main sprue. This allows for proper drainage of molten wax and maximizes the number of patterns on the tree. Always place the hard-to-fill items at the top of the tree (away from the button). It is best not to mix heavy and light pieces on the same tree. Remember that ideal flask temperature is directly related to the relationship of your metal's properties and the surface-to-volume ratio of the parts in the flask, so good judgment must be used when selecting the patterns that will be on the same tree. You can only have one flask temperature for all the patterns inside. If you are casting patterns with and without stones together, those with stones are best placed at the top of the tree and those without stones go toward the bottom.

## Investing Procedure

Stones must be clean before investing. Gently clean the stones of oil and contaminants by dipping and swirling the tree in denatured alcohol; make sure the tree is well dried prior to investing. When casting with diamonds in place, boric acid can be used to protect the diamonds from oxidation during burnout. The homogeneity of the investment and any protective additive is critical in ensuring that your diamonds are equally protected during the burnout process. Mixing the proper amount of additive with the water prior to mixing it with the powder ensures a homogenous mix. This is much more reliable than using premixed powders. Refer to your investment manufacturer's guide for mixing and timing instructions. Boric acid additions do not alter these parameters to any great extent. Boric acid in the investment mix is not necessary for most stones other than diamond, and is especially not recommended for Cubic Zirconia, as it can discolor them. There are investment additives that will give added benefits over simple boric

acid additions. These additives help eliminate residual carbon from low-temperature burnouts and alter the metal mold reaction. Adding boric acid or the other additives to investment typically makes it much stronger. These same boric acid additions can also make the investment mold crack if they are not homogenous, resulting in fins on the castings. These additives' added strength helps to resist spalling and investment inclusions common to cast jewelry. This property, along with the porcelain-like characteristics of these additions, give smoother casting surfaces. The gas-inhibiting properties of these additives also aid in casting difficult Palladium and nickel white gold alloys in standard gypsum-bonded investment. Since these additives makes investment stronger, it naturally increases the difficulty of removing the investment as compared to standard investment from the castings. The investment removal problem is compounded because the flask cannot be quenched hot with stones inside; the stones need to cooled slowly after casting. High-pressure water deinvesting cabinet systems and a little acid soak solves these problems.

## Burnout

The sensitivity of the stones being cast is the main factor to consider when deciding on a burnout process. Diamonds require a low-temperature burnout and that makes it difficult to remove all residual carbon from the wax out of the investment. While you may achieve success with casting the stones in place, you may also develop some slight gas porosity from the decomposition of the gypsum-bonded investment. This decomposition liberates SO<sub>2</sub> and O<sub>2</sub> gases and is compounded by the presence of carbon (from wax) in the investment that forms CO<sub>2</sub>. The heat from the molten metal starts the reaction after the metal is cast. As mentioned earlier, your additives reduce this effect.

After investing, the flasks should sit for at least two hours before placing them in a steam dewaxer. It is very important to remove as much of the wax prior to burnout as possible. Plan your investing and burnout schedule accordingly. Dewaxing is recommended in order to avoid the high temperatures necessary to burn excessive wax from the flask. Remove the flasks from the dewaxer and place them into youroven (preheated to 300°F). Hold at 300°F for at least two hours (three is better). Ramp at the rate of 180°F per hour, (about 3 degrees per minute) until you reach your top temperature.

Casting with diamonds in place in untreated investment using flask temperatures that never exceed 1000°F can be done with variable success. Since the success will be variable I don't recommend it. A properly modified investment flask can be taken to as high as 1200°F without causing damage

to the diamonds. Extend your top temperature dwell time as much as you can (up to five hours) to help carbon elimination. Ramp down to your casting temperature at approximately the same ramp rate of 3 degrees per minute. Hold your casting temperature for at least three hours (preferably four hours) depending on flask size and oven load. Extend this time when possible.

Cast at this temperature. When you have an oven full of huge ceramic and steel cylinders it takes a while for temperatures to stabilize throughout the cylinders and the oven.

## Casting

Generally, flask and metal temperature should be very accurate and at the minimum required to achieve 100% fill of the parts in the investment mold. Tests must be made to determine the optimum temperature, because gate and sprue designs—as well as surface to volume ratio of the pattern and alloy selection—all influence successful filling. When casting with stones in place, the maximum temperature the stones can take can control the flask temperature at casting. This temperature may even be cooler than the flask temperature normally used to cast the same item without stones.

Set the metal casting temperature for about 70°–80°C over the liquid temperature for gold and 80°–100°C over for silver. Of course you want your castings to fill and at that same time you want the surface of your castings to be as smooth and clean as possible. Accurate metal temperature at the time of casting is very necessary. Some casting machines are very quick and accurate, but most are not. With most machines the casting temperature of the metal needs to be approached slowly. Proper filling at cooler temperatures requires very clean metal without oxidation. Metal oxides and sulfides significantly increase molten metal viscosity and slows metal flow to the point that it freezes before it fills. Proper alloy selection is very important. Deoxidized alloys containing sacrificial elements such as silicon and zinc help reduce these metal oxides and the resulting oxide defects. Silicon containing alloys do have their drawbacks as well, and the caster should be aware of all tradeoffs involved in the use of metal with silicon additives. Deoxidized alloys are needed because of the limitations of polishing around cast-in-place stones.

Beware, silicon can enhance the grain size of the metal grains as they cool so much that they can actually impede metal flow in highly concentrated forms. Silicon in higher levels is known to increase the rate of porosity because it can weaken the grain boundaries of certain alloys. It can also

allow the pressures of the gas liberation of decomposing investment powder to add to any predisposition to shrinkage porosity caused by model problems.

Boron is an essential element in alloys that are for casting stones in wax. Boron can greatly enhance the fluidity of an alloy. You need as much fluidity as you can safely get because of the nature of diamonds to draw (sink) the heat out of the metal and cause non-fills in your castings.



## Cover Gases

Many different protective cover gases can be used. Inert gases such as nitrogen and argon are great. Forming gas (75% nitrogen and 25% hydrogen) can be used except with palladium white gold alloys. Palladium white gold alloys should only be cast using argon or nitrogen because platinum-group metals (palladium is a Pt-group metal) have an affinity for hydrogen, which can cause embrittlement.

Use the proper crucible materials for the particular metals you are using. Graphite crucibles work best with most copper containing alloys. Ceramic crucibles can be used with nickel and palladium white gold alloys with good results. I like to use boric acid when casting and making grain. In the case of graphite crucibles, the purpose of the graphite is to reduce metal oxides back to metal. If the graphite crucible is coated with molten boric acid it will make the crucible inert and will no longer reduce oxides. On the other hand, if there is a sulfide or oxide buildup in the metal due to metal mold reactions, the boric acid really helps get that out of the metal by combining with the boric acid and dragging it off and out of the melt. I am not sure which is the lesser of the two evils.

Some alloys have a problem in that they contain so much silicon that it will coat a graphite crucible without the use of any boric acid. The resulting material will combine with dust from the graphite crucible and form drops on the end of the sealing rod as the metal passes by—this dross clings to the rod and crucible.

On following casting cycles, when the flask is placed in the flask chamber and the crucible is put under 100% power, these carbon-containing drops of crud fall into the flask cavity. When the metal is added on top of that the drops are carried on into the castings where they are forced to the outside of the molten metal. The carbon in the drops combines with oxygen that is liberated from the decomposing investment to form gas pockets (with nice little black crud center spots). This gas liberation does not



seem to happen with boric acid but I have seen it with high-silicon alloys.

Let the flask stay in the vacuum chamber after the metal has been poured for up to one minute with the vacuum applied after casting to allow for maximum gas removal and temperature equilibrium. Put the cast flasks aside and allow for slow gradual cooling of the stones in the investment to room temperature before divesting. Do not rush this cooling or you can fracture the stones!

## Finishing

High-energy mass finishing machines are not recommended for stone-in-place castings. While these machines are great machines they can, in some designs, cause the stones to make contact, increasing the risk of abrasion. Chemical polishing works but the drawback to this method is that it can remove metal around the stones and make them loose. Magnetic finishing using fine pins (burnishing) works well for stone-in-wax castings. Areas around the stones that are cast in place are difficult to access in most conventional manners. Conventional polishing techniques can be used for the remainder of the ring. Use caution when using aggressive compounds on your buffs as these compounds may dull some stone surfaces.