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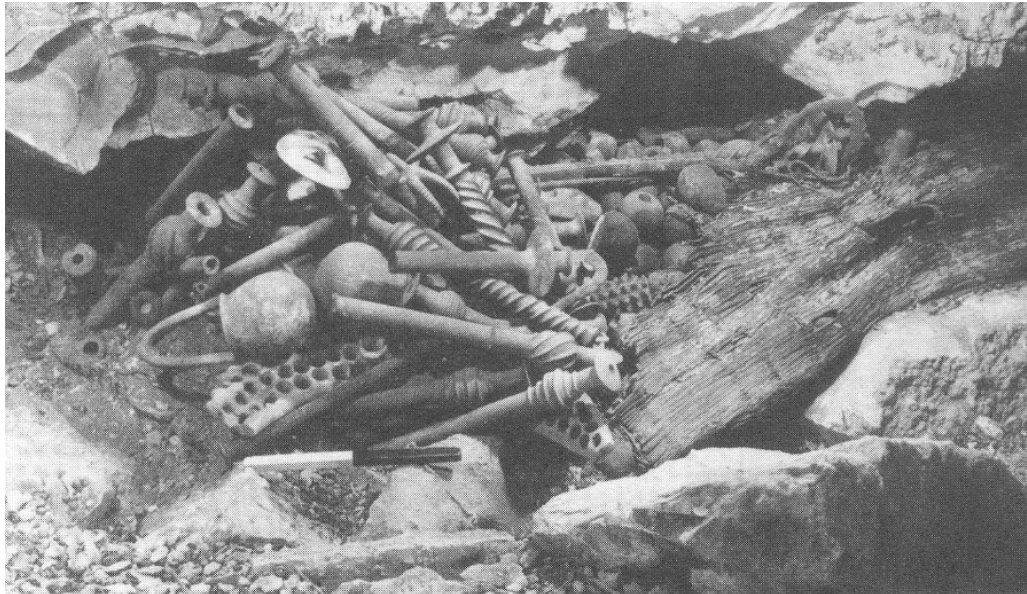
Eddie Bell is Chairman of Neutec/USA and co-founder of the Santa Fe Symposium on Jewelry Manufacturing Technology. He is generally appointed as SME in the jewelry industry, and he is considered one of the most knowledgeable specialist in the process of lost-wax casting. He has delivered papers at several international conferences on jewelry technology, always presenting original analyses enriched by lots of practical aspects.

*Using investment cores to cast hollow objects with the lost wax method is certainly not new; it has been practiced for at least 5500 years. The recent rise in precious metal prices has caused renewed interest in hollow casting to produce attractively large yet lightweight jewelry. This paper will discuss historic practices for hollow casting and how recent technical innovations collaborate to reduce the difficulty experienced in the past, while expanding the design possibilities that make cast hollow jewelry an attractive alternative in the current market.*

## Casting Lightweight Hollow Jewelry Using 21<sup>st</sup> Century Technology

### History

In 1961 a remarkable cache of sacred treasure was found near the Dead Sea by Israeli archeologists. The treasure is remarkable because it is the oldest yet found and by far the largest and the most varied (442 pieces, 429 of them are cast metal). In figure 1 you can see the cache as it was, wrapped in a straw mat, when found in what is known as the Cave of Treasures. Because of the straw mat the cache was easy to carbon date to 3500 B.CE.<sup>1</sup>



*Figure 1. Cache from the Cave of Treasures shown as it was found near the Dead Sea in 1961. The straw mat was carbon dated to 3500 BCE.*

The perfection of craftsmanship and great artistry of the objects are remarkable as can be seen in figures 2 & 3.

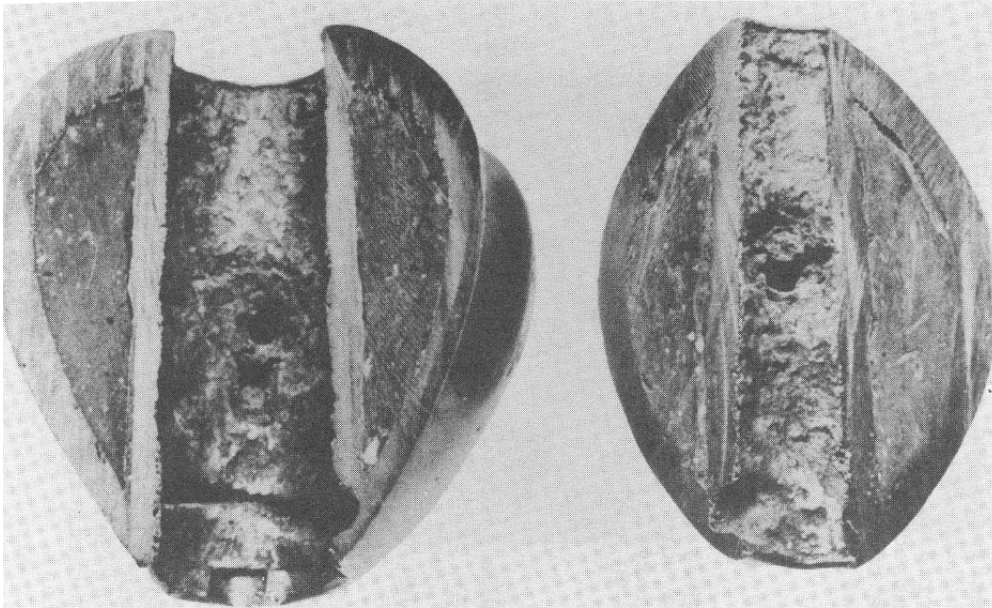


*Figure 2. Standard depicting a locally found mountain goat called an Ibex. It is 11cm high and is cast using a copper-arsenic alloy.*



*Figure 3. Jar 16cm high cast in copper-arsenic alloy. These objects are presumed to be ritual artifacts.*

But of interest here are the many mace-like objects that were found. They appeared to be a solid piece but have too little mass for their size to be solid castings. Because there were so many of these mace-like objects, it was decided that what could be learned by cutting one open outweighed the loss of an ancient artifact. In figure 4 we see a Copper Age mace that was hollow cast using the lost wax method with the investment material used for the core still inside the casting. Why did the caster bother to make a hollow casting rather than a solid one? Was it because the metal was preciously rare and hollow casting provided a high volume-to-weight ratio? Was it because they knew so long ago that thinner sections cast with fewer defects than thicker sections? Or was it an engineering decision, making the mace head lighter in order to achieve better balance on its handle?



*Figure 4. Mace cast in copper-arsenic with investment core still in place. There were so many objects that one could be sacrificed to study the core material.*

Fast forward about 3500 years to a ring attributed to the Roman Empire that appears to be hollow cast in gold (figure 5). I saw this ring at the Hermitage in Saint Petersburg. The curator was kind enough to send me a photo of it but was not inspired to cut it open to see if it contained a core. However, he speculated that due to its lighter than expected weight we might assume it to be hollow. So we can see that even if we refine our search to hollow cast jewelry, we have to go back at least 2000 years. Again, we have the same questions as to why bother to make a hollow cast. Was it to conserve metal, or to get uniform thickness for easier casting or was it for balance—to keep the ring top from turning to the palm of the hand? We will never know, but these questions are still relevant thousands of years later and they are all valid reasons to make hollow casting today.



*Figure 5. Roman ring appears to be hollow cast in gold.*

### Hollow casting then and now

In ancient times the process to make a hollow casting would have been slow and laborious. The pattern and sprues could have been made of beeswax. The literature says the investment in the core of the mace contains 57% calcium carbonate (chalk) and they suppose powdered charcoal. The charcoal would have burned out, providing permeability. It doesn't say what the remainder of the mixture is. We can reconstruct the mace casting starting with building the pattern and core. The wax tube surrounding the handle could have been made using the actual wood handle to be inserted later as a mandrel (figures 6 & 7).

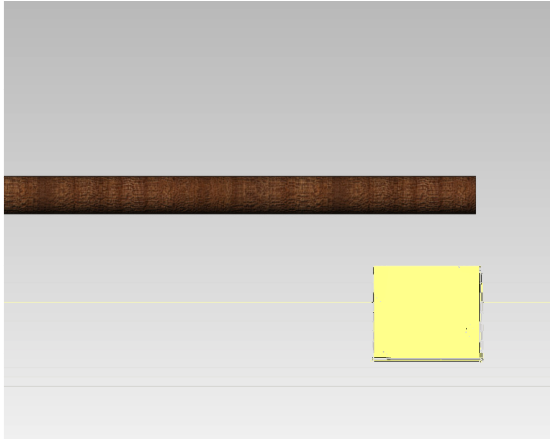


Figure 6. Wax sheet wrapped on mandrel



Figure 7. Wax sheet wrapped on mandrel

Then the investment core could be built on top of the wax and carefully dried. Once the investment core was dry and hard it could be used as a mandrel and covered with wax to complete the pattern (figure 8).

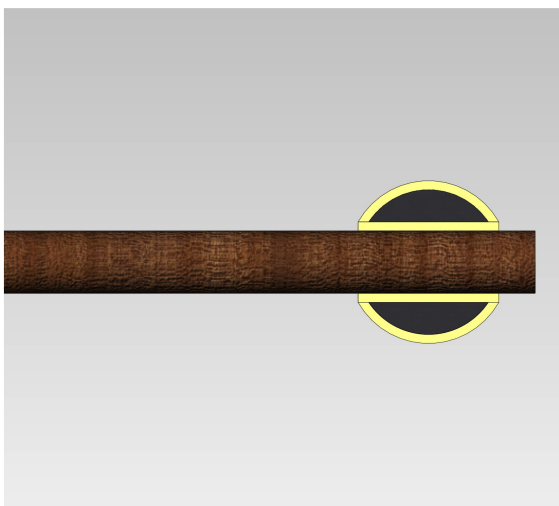


Figure 8. Section view of wax pattern covering the investment core

At this point the wax pattern could be removed from the wood handle and chaplets inserted to keep the core from shifting (figure 9). Sprues could be attached along with a large wax funnel where the metal would be melted (figure 10). Chaplets can have many forms, the simplest being a piece of wire made of the same material that is being cast.

As you will see later, core shift can be controlled without chaplets if parts of the core extend through the wax pattern to the outer mold cavity. In jewelry casting it is desirable to remove the core after casting so some kind of hole is necessary and it might as well be used to locate the core too. Most jewelry casters also have laser-welding equipment, which can be used to invisibly plug core holes after casting.

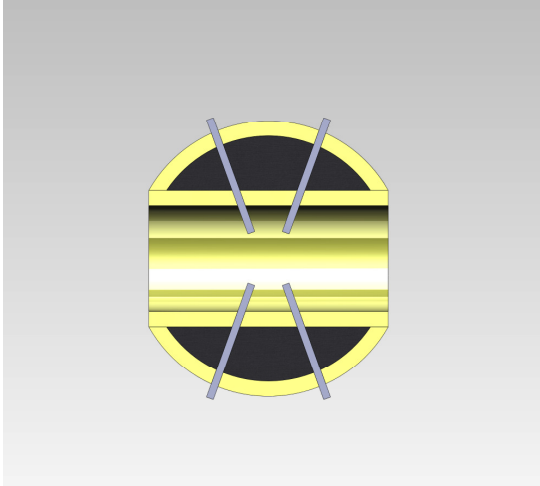


Figure 9. The pattern removed from the wood handle (mandrel) with the chaplets installed to prevent the core from shifting

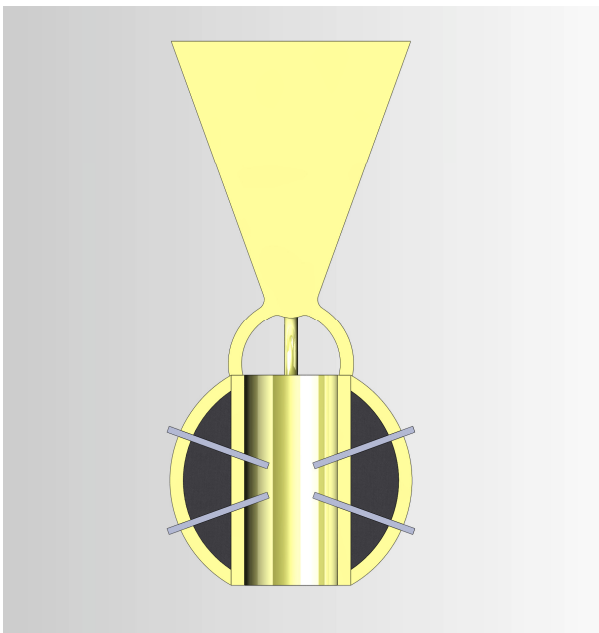
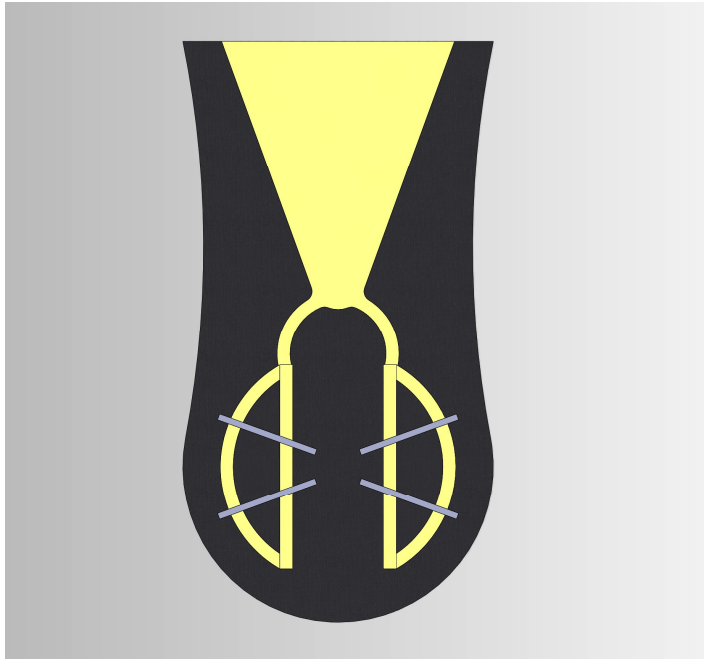


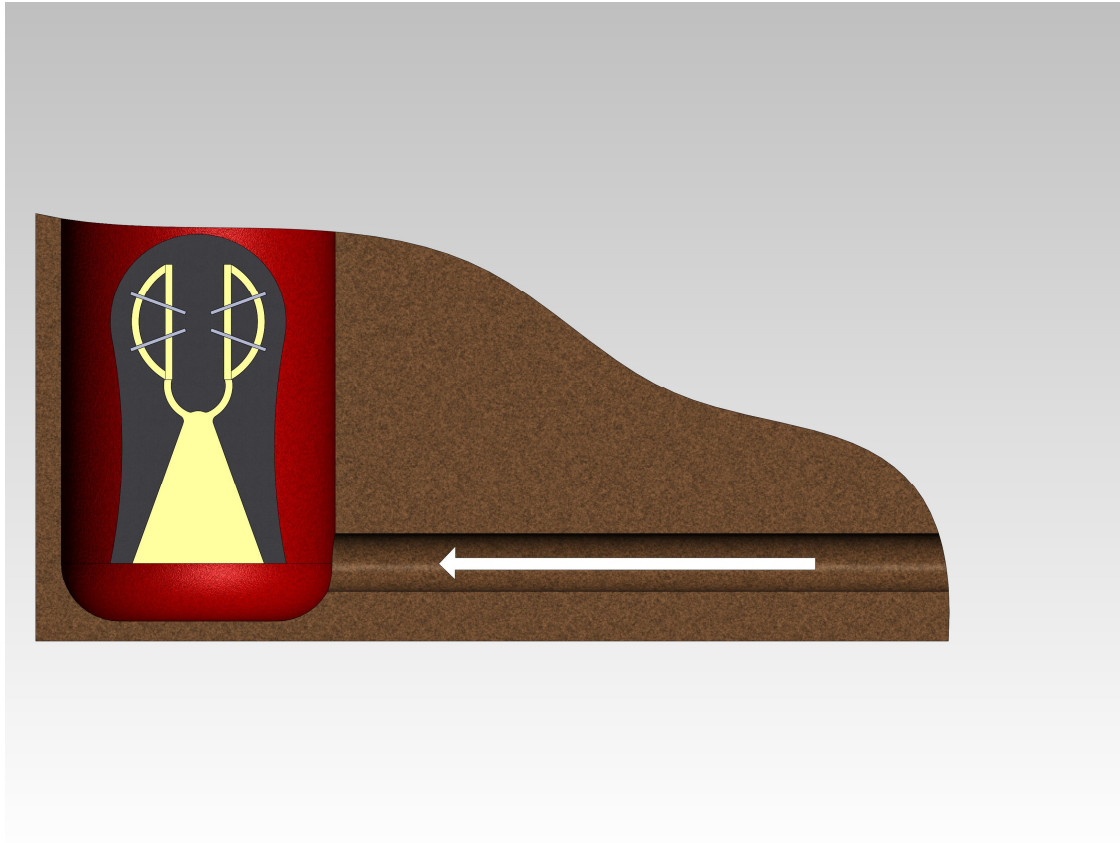
Figure 10. A sprue network and a large wax funnel are attached to the wax pattern, making it ready for investing.

The next step would be to pack investment inside the handle hole and all around the outside, leaving the funnel mouth opening for the wax to exit (figure 11).



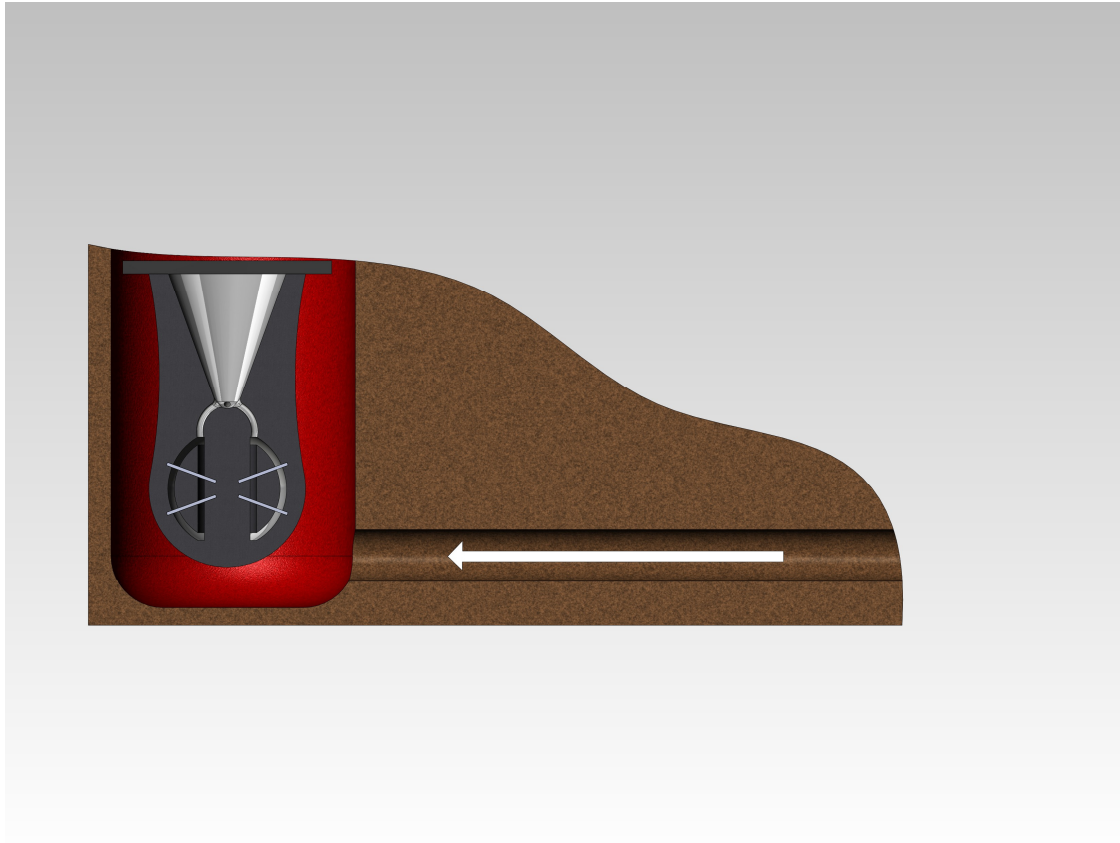
*Figure 11. A section view of the invested mace pattern*

I don't know how the metal was cast in the Cave of Treasures artifacts, but I speculate that it could have been done similar to a method still practiced on the Gold Coast of Africa. They build a furnace in the ground and that is supplied with air at the bottom through a tube. They fire the mold to burn the wax out and completely dry the investment (figure 12).



*Figure 12. A furnace built in the ground with a tube feeding air to the bottom.*

After the burnout they place the metal in the funnel with some charcoal and cap it with more investment. They then heat the whole mold in the charcoal furnace until the metal melts and trickles down to fill the pattern cavity (figure 13). When they judge the metal has completely melted, the fire is extinguished and the casting can be broken out of the mold when it has cooled.



*Figure 13. The metal trickles into the pattern cavity as it is melted.*

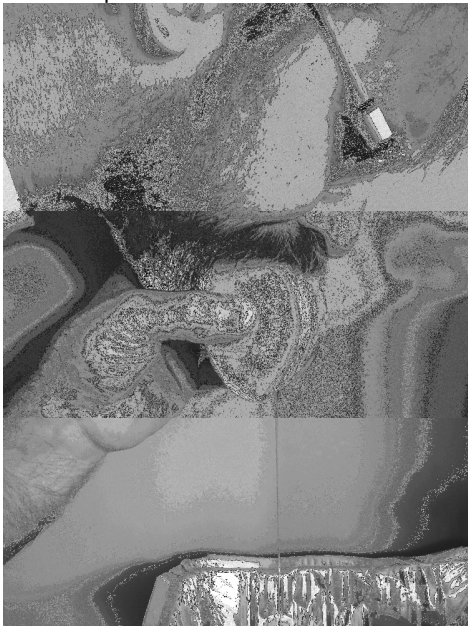
### **Making hollow wax patterns the simple way**

The easiest way to make hollow casting by the lost wax method is to fill a mold with wax and, after a thickness of wax has solidified in the mold, the remainder of the wax is poured back out, leaving a hollow core that can be filled with investment. The incredible goldsmith and enamellist David C. Freda<sup>2</sup> used this method to make eggshells for his hatching snake necklace (figure 14).



*Figure 14. Hatching snake necklace by David C. Freda*

In figures 15 and 16 you can see him blowing the liquid wax out of the rubber mold and the resulting hollow wax pattern. This is a simple technique requiring little model making and molding effort, but control of the wall thickness is almost impossible.



*Figure 15. Blowing the wax out of the mold*

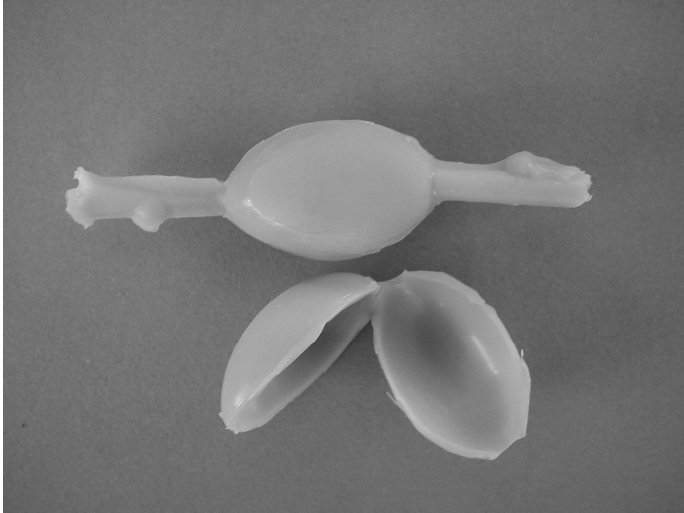


Figure 16. Hollow wax patterns

### **Water-soluble wax mandrels**

When precious metals are cast in production, control of the weight is important and that need led to the next innovation. That was to make a mandrel from an injectable water-soluble wax that a wax pattern can be molded around. The water-soluble wax is dissolved, leaving an empty core in the wax pattern that can be filled with investment. In the last 50 years production hollow jewelry has been cast by the lost wax method using water-soluble wax for the core mandrel. Rubber molds and water-soluble wax made the process much easier but there was still a great amount of skill needed to make patterns and cores that fit perfectly, and the castings were rather heavy to compensate for off-center cores.

### **Twenty-first century tools make it possible**

In the past ten years we have seen a revolution in the tools used to make jewelry models. Computers and high-resolution monitors capable of running CAD are 1/7 the cost of 20 years ago and more than a thousand times faster. The CAD programs are also much less expensive, more intuitive and powerful. Tabletop CNC milling machines have become faster and more precise. Rapid prototype machines have progressed to become rapid manufacturing machines. At the same time they have become cheaper to run and the product from them is much better. And yes, even the wax injector and the mold compound are new and better. Finally, while not so new, laser welders and magnetic pin finishers have become much better and lower priced. These tools, along with high-strength silver, gold and now platinum alloys, create opportunities to make high-volume/low-weight jewelry that never existed before.

### **Hollow core casting**

While hollow casting can be applied to all sorts of jewelry items, a simple bead shown in figure 17 will suffice to illustrate the process.

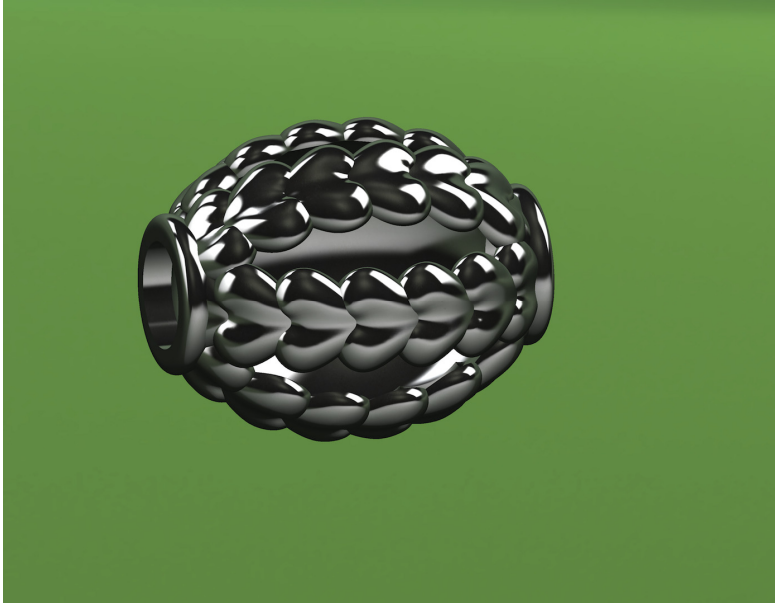
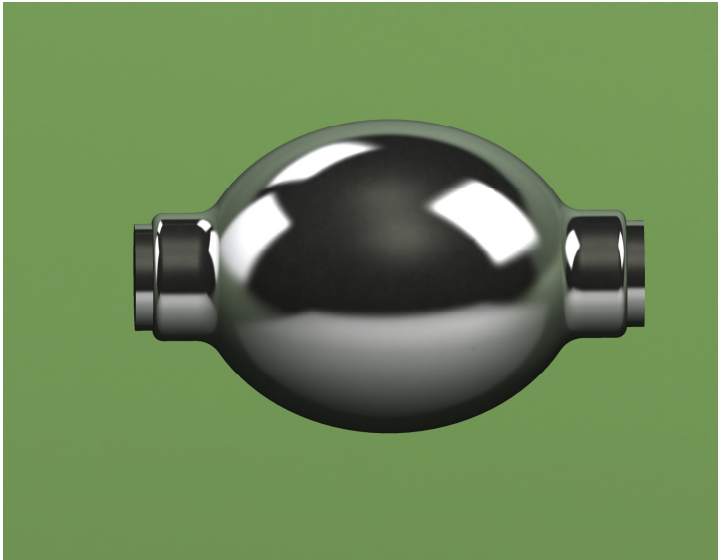


Figure 17. A CAD image of a hollow bead design.

With SLA technology, this item can be grown as a hollow resin pattern and directly cast. This is the most economical way to make such an item if a small quantity is needed. However, if a large number is needed, then there is economy in making molds for wax injection. Two molds will be needed, one for the core and the other for the bead. The volume of the bead core can be very precisely determined in the CAD program. The master model needed for the core can be stripped out of the inside of the bead and either machined in carving wax or grown. If it is a simple core like the one shown in figure 19, it could also be machined in metal ready to be molded. In this case the core is located by the extension of the stringing holes in the bead. In other jewelry items core holes can double as stone setting holes or be decorative, such as heart-shaped holes on the inside of a ring or bracelet.



Figure 18. SLA-grown resin pattern for direct casting



*Figure 19. Core master model*

The mold can be made on the core master model and injected with water-soluble wax. The water-soluble wax is quite hard when it cools so it does not distort easily when placed in the mold for the bead injection. Notice that this core is located by extensions protruding through the stringing holes on both ends. Some feature is needed to locate the core in the casting pattern mold.

The master model for the casting pattern must have the core inside as seen in figure 20. Notice that the same locating features that are present on the core master model must also be included on this master model.



*Figure 20. The master model for the casting pattern must have the core included with the locating features.*

When the molds are ready the core mold is injected using water-soluble wax (figure 21). Then the water-soluble wax core is placed inside the casting pattern mold and injected with pattern wax (figures 22 & 23). Generally, a tree is constructed with the cores still in the casting patterns and then the cores are dissolved out, leaving the wax pattern

hollow. Provided the penetrations from the wax pattern to the core are large enough, it is possible for investment to fill inside and outside of the pattern at the same time.



Figure 21. Water-soluble wax core.

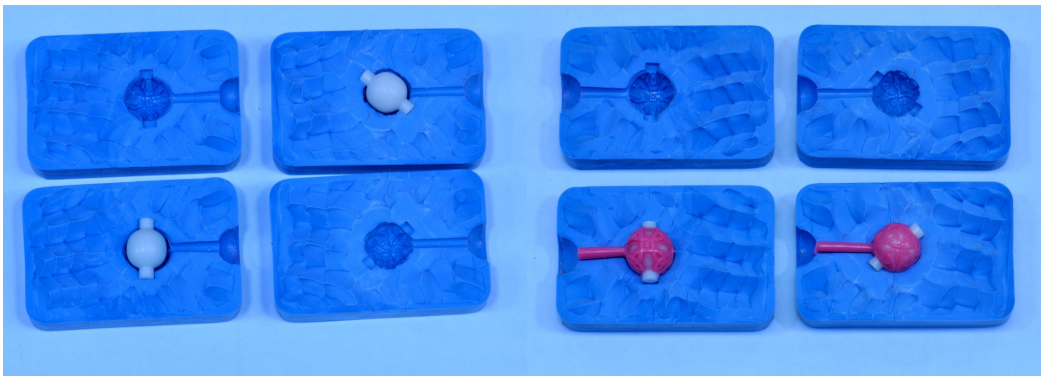


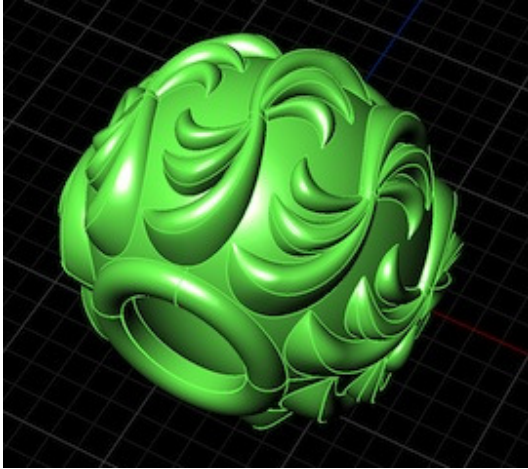
Figure 22. Core in wax pattern mold

Figure 23. Wax pattern injected on core

## Weight

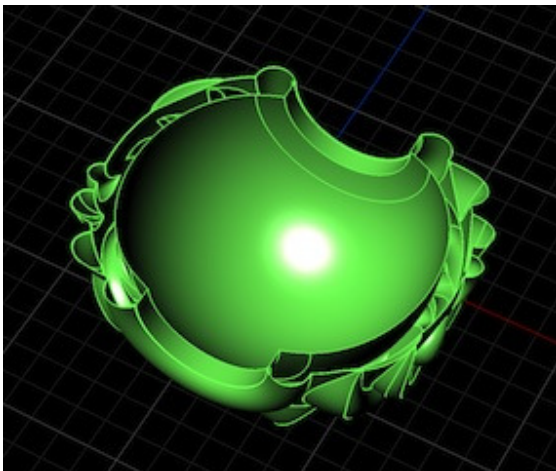
The recent rise in the market price of precious metals is making everyone think about making thin-walled items to reduce metal weight. Hollow casting is well suited to designs that have volumetric appearance but are lightweight. In addition to the computer-driven design and production tools now available, we have a whole range of new gold and silver alloys that can be hardened by heat treatment. These new alloys<sup>3,4</sup> demonstrate that very thin-walled items that are hardened are as durable as the same item would be made from a normal alloy that is thicker and heavier.

A study of the bead shown in figure 24 provides insight into what is possible and where some problems could arise. The bead has a diameter of about 13mm and a wall thickness of 0.75mm and it was designed to have a nice hefty feel. With today's high precious metals prices, "hefty" isn't nice anymore; today, the same volume and less weight is nice.



*Figure 24. CAD image of a bead*

One great advantage of designing jewelry using a CAD program is that with a few keystrokes the properties of the design are available. The program can calculate the total volume of the design, which can be multiplied by the density of the material to get the mass. This feature is very useful when a target weight is desired. For example, as mentioned before, this bead (figure 24) has a diameter of about 13mm and a wall thickness of 0.75mm. Actually, that is a minimum wall thickness; where the design features are raised, thickness and therefore weight are added. A skilled CAD designer can quickly change the design inside the bead, leaving the outside unchanged, and then see what the change in weight would be. In figure 25 we see the original bead design sectioned and the minimum wall thickness reduced to 0.50mm. The inside is still spherical and results in a weight reduction of nearly 20%.



*Figure 25. Original bead design sectioned and reduced to 0.50mm wall thickness*

In figure 26 the outside design contour was copied and scaled down to fit inside the outer shell with a wall thickness of 0.50mm. This results in a weight reduction of 45% from the original design.

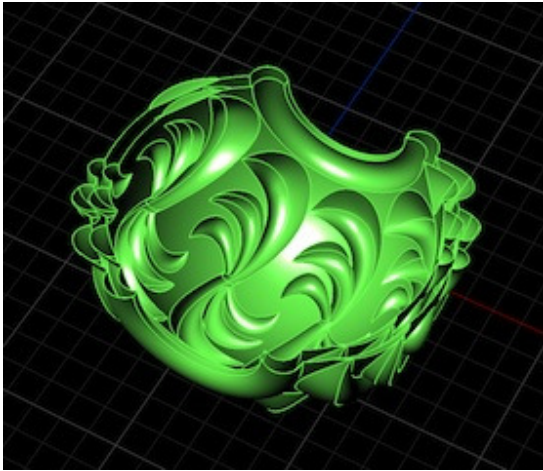


Figure 26. The original bead with the inside contoured to follow the outside design features

In figure 27 we see a composite of the bead design with the original spherical core and the two thinner wall contoured cores. Table 1 shows the weight of the bead in 18K gold and sterling silver for each of the iterations illustrated in figures 25 to 27. The thinnest wall design has a mass that is 70% less than the original.

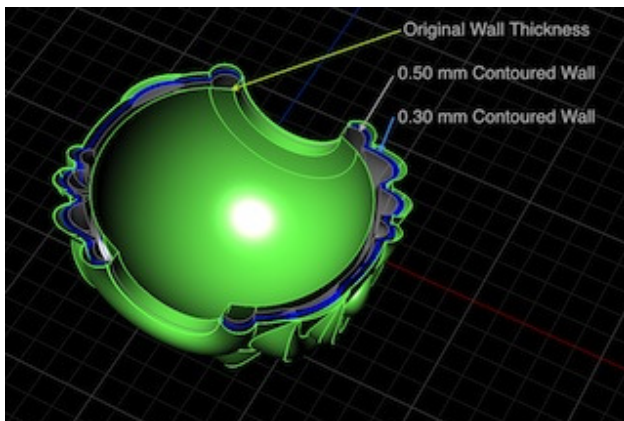


Figure 27. Composite CAD image showing the original design and the two thinner wall iterations derived from it.

Table 1. Bead weight change

Wall thickness mm	Weight grams (spherical inside)				Weight grams (contoured inside)			
	750 Au		925 Ag		750 Au		925 Ag	
	wt	%Δ	wt	%Δ	wt	%Δ	wt	%Δ
0.75	5.91		3.96					
0.50	4.75	-19.6	3.18	-19.6	3.25	-45	2.18	-45
0.30					1.80	-70	1.20	-70

However, close examination of the CAD model exposed a flaw that would have made the model impossible to grow in a SLA machine and, if the core were machined, the core would not fit in the wax pattern mold properly. This is due to the use of scaling.

Scaling is a favorite tool of the CAD jewelry designer. One of the benefits of computer design is the ability to make a design and then scale it larger or smaller, for example, a pendant and earrings of the same design. If the scaled object is going to be cast as a solid piece, the problem that scaling poses might not be noticed or attributed to post processing, but when making hollow designs, it often doesn't work. Scaling is a percent change of an object, which sounds simple enough. The problem is that in scaling mode, most CAD programs can only change the geometry in

one direction. To scale the outer shell smaller to make the inner shell, it would shrink the image toward the center of the bead. This means that the relationship between inner and outer tangent lines will be different than radial lines. This difference can be seen in figure 28, where three points on a section of our scaled (supposedly 0.30mm wall) CAD image have varying wall thickness depending on the direction of scaling and whether the geometry provides tangent or radial lines. We can see that the effect of moving radial lines toward the center does not increase the wall thickness at the same rate as tangent lines. By the way, scaling of CAD images is often the root cause when SLA resin patterns grow distorted or incomplete.

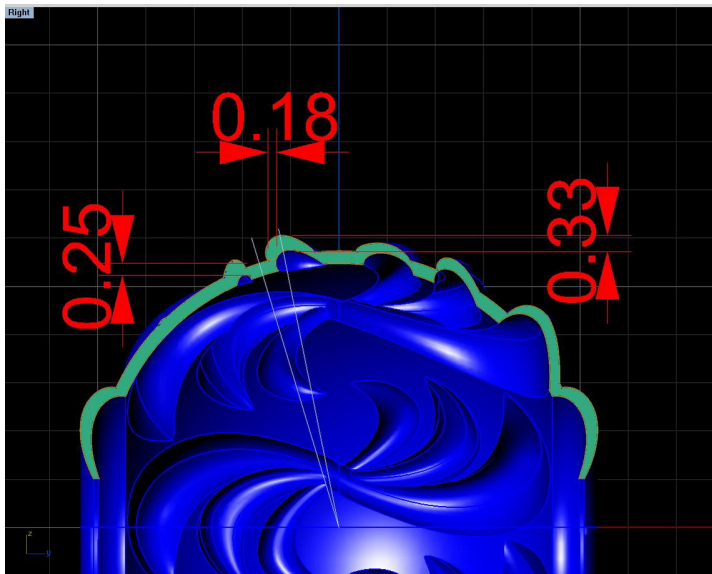


Figure 28. Three points on a scaled object show the effect of moving toward one point. Tangent lines scale as you would expect but radial lines do not move apart.

When the model is expanded on the computer screen we can see in figure 29 that there is an undercut that causes a portion of the outer shell to penetrate the inner shell.

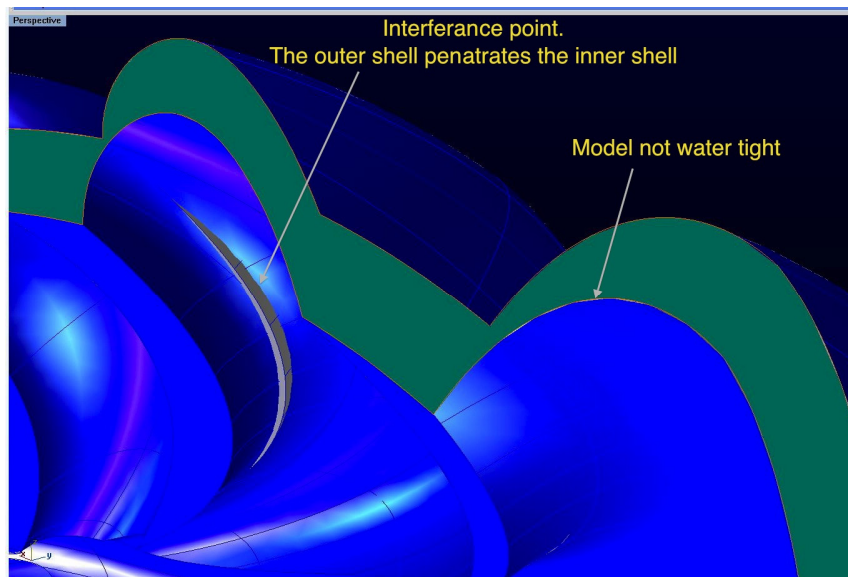


Figure 29. Interference point. The outer shell penetrates the inner shell

There are a number of CAD programs and they all seem to have their advantages and disadvantages. We use six or seven different programs because none of them is all encompassing, and different users have preferences. Jewelry designers seem to prefer programs that allow easy free-form capability. There are several jewelry specific programs based on Rhino®, which started as a design tool for shipbuilders. Matrixs®, RhinoGold® and T-Splines® are among the Rhino-based programs. ArtCAM JewelSmith® started as a tool for sign makers and is especially good for 2½D work or converting flat art to dimensional art. It also has a solid CAM driver for tabletop wax milling machines. 3Design® is a true solid modeler made specifically for jewelry design. It has the free-flow capability combined with the advantage of solid models.

SolidWorks® is a very powerful and robust CAD program for engineers. It is not good for drawing free-form images but jewelry designers are starting to realize its worth for getting an image ready for machining. They use free-form programs to draw their design and then import the image into SolidWorks before it is sent to a CAM program. One of the weaknesses of the Rhino-based programs is the models often have little gaps that make them not be watertight. You can see in figure 29 an example of such non-watertight gaps in that model. A milling machine would think the tool should dive into that gap and would likely crash the spindle into the table. It would be difficult to draw the bead shown in figure 24 using SolidWorks, but it has a wall offset tool that in a few minutes can make the inside of the bead contoured to the outside with a perfectly uniform wall thickness. Matrixs and 3Design have offset tools but they don't work well and waste a lot of time. It is important to understand the attributes of these programs to avoid headaches as the wall thickness get thinner and the working parameters more precise.

### **Shrinkage**

Knowing how much shrinkage to expect from each material and each step of the process is critical. Is your shrinkage data for your wax and molding compounds up to date and accurate? Water-soluble wax has a rather noticeable shrinkage of solidification and therefore exhibits shrinkage sink on the surface. When the core is not full size, the pattern mold doesn't seal off tightly on it and the wax fills space that should be void, causing flash or finning. One trick is to cast two water-soluble cores, one a half millimeter on a side smaller than the needed size and use built-in chaplets so it is held centered in the second core mold. The final core is injected around the inner core, resulting in a core with no shrinkage sink. Cores are usually simple geometry so it is best to use a hard mold compound such as a 57 Shore A durometer. The core must fit snugly in the wax pattern mold so injection wax doesn't flow where it shouldn't but not too snug to prevent distortion. This kind of precision would be very difficult without the use of CAD design and computer-driven manufacturing.

### **Direct casting of hollow SLA patterns**

In recent years the surface finish of SLA resin patterns has improved greatly. This makes direct casting of hollow SLA patterns more interesting because the inside surfaces, where it is difficult to polish, can be made attractive using just pin finishing. The most interesting use of directly casting production products using SLA patterns is for making designs that can't be cast any other way. This raises the design innovation bar and provides the buying public something truly new.

### **Casting and assembling verses hollow core casting**

Some designs are best made by casting two or more parts and assembling the pieces by soldering or laser welding. If having a high polish on the inside is important, this is the only way to do it. From a cost standpoint, this might be more or less economical. There are extra steps in casting with a hollow core that might be equally offset by assembly so the decision might be made based on the design. If having a visible seam does not detract from the design, then assembly might be the best option. If the design looks better with no visible seam line, then casting on a core will win.

### **How thin can it be?**

I wish I could answer that question but there are too many variables that must be considered. First, how thin can the metal be and still hold up? That depends, of course, on how hard the metal is of course; the harder the metal the thinner it can be. A few years ago I would have said that when it comes to thinness the limitation wasn't the casting of the metal, it was producing a thin wax pattern. New wax injector technology from Riace has changed that. I am very

impressed with these machines. They are a bit slower than vacuum injectors with auto clamps, but at the end of the day we have more useable wax patterns. And it will inject a very thin pattern if you have a good mold. At the Santa Fe Symposium® in 2009, our dear friend Dr. Hubert Schuster showed us a method for making molds using multiple durometer compounds to produce thin, exact-weight wax patterns<sup>5</sup>. The technique requires silicone compounds that offer various durometers all with the same shrinkage factor. So I don't know how thin we can cast, but I can say that as a practical matter it is getting thinner.

### **Conclusion**

So 2000 years later, we can speculate about why they bothered to hollow cast a ring. Was it to conserve metal, or to get uniform thickness for easier casting or was it for balance—to keep the ring top from turning to the palm of the hand? We will never know, but these questions are still relevant today. If this were a multiple-choice question, we could check “all of the above” and be right. The important thing to know today is what the possibilities are and see how they fit into your business model. Whether your product is one-of-a-kind platinum or high-production silver or something in between, there is something new you can make using these tools and meet a price point too.

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<sup>1</sup> Schneller, D., “The Cave of Treasures—Lost Wax Castings from 3500 B.C.,” *The Santa Fe Symposium on Jewelry Manufacturing Technology 1987*, ed. Dave Schneller (Boulder, Colorado: Met-Chem Research, 1988): 1.

<sup>2</sup> Freda, D., “Hollow-Core Casting for the Jeweler/Enamellist: Vacuum Casting Method,” *The Santa Fe Symposium on Jewelry Manufacturing Technology 2003*, ed. E. Bell (Albuquerque: Met-Chem Research, 2003): 49

<sup>3</sup> Raykhtsaum, G., “Age Hardenable 14-Karat White Golds”, *The Santa Fe Symposium on Jewelry Manufacturing Technology 2011*, ed. E. Bell (Albuquerque: Met-Chem Research, 2011): 489

<sup>4</sup> Raykhtsaum, G., “Age Hardenable Colored Karat Golds”, *The Santa Fe Symposium on Jewelry Manufacturing Technology 2009*, ed. E Bell (Albuquerque: Met-Chem Research, 2009): 343

<sup>5</sup> Schuster, H., “Innovative Mold Preparation and Cutting for Very Thin and High Precision Items”, *The Santa Fe Symposium on Jewelry Manufacturing Technology 2009*, ed. E Bell (Albuquerque: Met-Chem Research, 2009): 359