



WHAT YOU DON'T KNOW CAN HURT YOU!

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In this paper, I will again be discussing cause and effect relationships of many common jewelry manufacturing defects. Just like the many defects that are commonly mislabeled as porosity that were discussed in my 2002 paper, this year I will talk about other types of recurring defects that are often misdiagnosed. I will try to avoid going back over defects that I covered in 2002, but there are some issues that deserve to be reinforced.

TECHNICAL MODEL MAKING

CAD-CAM

With the incredible growth in CAD-CAM model-making in the jewelry industry over the past few years, there are increasing numbers of CAD model-related defects that are coming to light. A lot of this is due to a growing number of fresh CAD operators who lack experience and training in jewelry manufacturing, mechanics and physics. Many of these new CAD operators are not required to spend time in the hands-on jewelry manufacturing operation. It is not practical to train every new CAD operator in all the peculiarities and skills of jewelry manufacturing before they start pulling their weight as a model maker. It would also be expensive to assign experienced hands-on model makers to every new CAD operator. I do believe, however, that it is in the best interest of any competitive jewelry manufacturing company to have the hands-on model makers, the production line heads, and these new CAD people to interact regularly on all new CAD designs. It will be this kind of feedback that will sharpen the learning curve and keep the new style production flowing smoothly.

But, it is not only inexperienced CAD operators who contribute to the CAD defect pool. Many forward thinking companies have progressed to using 3- and 4-axis mills to carve and print many of their new styles. Most of these CAM model materials have properties that challenge conventional investment casting methods. Some of the various materials that are being used for CAM models are formulations of carving wax, printing wax, and plastics. While there are newer technologies under development right now, we will be discussing the more common varieties. Carving waxes tend to crack regular gypsum-bonded investments, causing investment inclusions in many hand- and CAD-CAM-carved models.

Printing waxes have fewer of these problems, but they have problems all their own. Investment inclusions are one of the first places where defects start to affect your whole production process. If your CAD operator has designed the model with the rules governing cooling metal in mind, repairs caused by casting defects can distort these technical functions. Repairs to models in general often cause such a gradual change in production performance of a given style that it often goes unnoticed until it gets critical to your production, or is noticed by your customer.

MODEL MATERIALS

Silver Solder

In conventional fabrication of models for the jewelry business, the use of sterling silver and various grades of silver solder is standard. Considering the exposure of these carefully crafted original models to surgical blades, chemicals, and mishandling, soft sterling silver just doesn't seem to be a good choice of material. The sulfur content in most production molding rubbers attacks the surface of both the silver and copper content of sterling alloys. Silver solders (Table 1) typically have less silver, more copper and other reactive metals, such as zinc and tin, to lower the melting temperature. Most of the rubber manufacturers that I talked with claimed that their rubber would not cause pits in a silver model or the solders. That information does not seem to match my experience (Figure 3). Having carved and fabricated models for years myself, I always questioned the use of these materials, but like so many, it was what had always been done, it was comfortable, and I continued. Now that I am a little older and hopefully wiser, I would like to suggest a reconsideration of these common practices. One relatively easy change is the use of gold solders instead of silver solder for your models.

Table 1 Some typical solder formulations

| Solder Type | Ag % | Cu% | Zn% | Sn% | Cd% | Melt Temp F° | Melt Temp C° | Flow Temp F° | Flow Temp C° |
|--------------|-------|-------|-------|------|-------|-----------------|-----------------|-----------------|-----------------|
| Easy Flo #30 | 30.0% | 27.0% | 23.0% | | 20.0% | 1125 | 607.22 | 1145 | 618.33 |
| Easy Flo #45 | 45.0% | 15.0% | 16.0% | | 24.0% | 1125 | 607.22 | 1310 | 710.00 |
| Braze 560 | 56.0% | 22.0% | 17.0% | 5.0% | | 1145 | 618.33 | 1205 | 651.67 |
| Braze 650 | 65.0% | 20.0% | 15.0% | | | 1240 | 671.11 | 1325 | 718.33 |
| Braze 700 | 70.0% | 20.0% | 10.0% | | | 1275 | 690.56 | 1360 | 737.78 |
| Braze 750 | 75.0% | 22.0% | 3.0% | | | 1365 | 740.56 | 1450 | 787.78 |

Table 2 *Melting and flow point of some gold solders*

| Karat | Color | Designation | Melt F° | Melt C° | Flow F° | Flow C° |
|-------|--------|-------------|---------|---------|---------|---------|
| 14 | White | Hard | 1430 | 762 | 1550 | 829 |
| 14 | Yellow | Hard | 1400 | 746 | 1500 | 801 |
| 14 | White | Medium | 1375 | 732 | 1500 | 801 |
| 14 | Yellow | Medium | 1330 | 707 | 1450 | 774 |
| 14 | White | Easy | 1310 | 696 | 1450 | 774 |
| 10 | Yellow | Hard | 1300 | 690 | 1425 | 760 |
| 14 | Yellow | Easy | 1290 | 685 | 1390 | 740 |
| 10 | White | Medium | 1290 | 685 | 1415 | 754 |
| 10 | Yellow | Medium | 1280 | 679 | 1400 | 746 |
| 8 | White | Easy | 1275 | 676 | 1400 | 746 |
| 8 | Yellow | Easy | 1275 | 676 | 1400 | 746 |
| 10 | Yellow | Easy | 1230 | 651 | 1375 | 732 |
| 14 | Yellow | Super-easy | 1180 | 624 | 1330 | 707 |

Before you start thinking about the expense of gold solders as compared to silver solders, consider the repair time that a pitted model can cause. How much is that worth? Gold solders come in a variety of karat values and melting temperatures and are much less susceptible to pitting. Table 2 should help you to compare and try some alternatives. Don't forget, when you make this suggestion to your model makers, that most folks view change as a bad thing and tend to be resistant. Make sure that the experimental method is incorporated when you introduce this concept.

Sterling Models

Besides using gold solders on your models, I would also suggest consideration for lower temperature versions of chrome cobalt or nickel-based alloys for model making. Some believe that the use of nickel alloys for consumer jewelry is not ideal; it is not, however, an issue for making the original models. Casting these types of metals would require some different equipment and considerations by model makers, but I feel the results can be beneficial. The melting and casting temperatures of most of these alloys are in the 2500°F to 2700°F range, and would prevent them from being cast in gypsum-bonded investment powders. There are nickel alloys available that cast at a lower temperature and can be cast in CaSO₄ bonded investment, but they contain beryllium. You need to know what you are doing if you work with beryllium—it is one of the most deadly metals known and it is a cumulative poison. Once in the body, beryllium never leaves and you don't know you have a problem until it is too late. It is my hope that someone takes this as a project and makes a better model metal for cast and even fabricated models.



Figure 1 Carving Wax

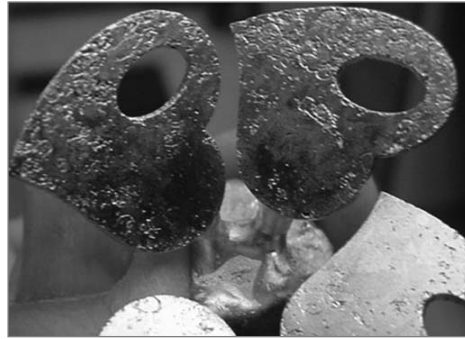


Figure 2 Carving wax with smooth injection wax feed sprues

CAD-CAM WAX DEFECTS

All commonly used jewelry waxes have essentially the same ingredients in varying amounts to give the desired properties. When compared to injection waxes, carving waxes have a higher density, thus a higher melting temperature. The thermal expansion percentage of carving wax and that of injection wax is probably the opposite of what most people think, especially those of us who have been experiencing lots of these defects. Most people are currently under the impression that carving wax has a higher percentage of volumetric thermal expansion than does injection wax, and that it is breaking the investment and causing these defects. As a matter of fact, injection waxes have a higher rate of thermal expansion than do carving waxes (see Table 3). Plain paraffin has one of the highest expansion rates of all the “waxes.”

Table 3

Wax properties

ND = No Data

| Machinable Carving Wax Example | | 3D Printing Wax Example | | Standard Injection Wax Example | | Plastic Containing Injection Wax Example | |
|--------------------------------|----------------|----------------------------|---------|--------------------------------|----------------|--|-----------|
| Hardness (Shore D scale) | 55 | Hardness (Shore D scale) | 55 | Hardness (Shore D scale) | 44 | Hardness (Shore D scale) | ND |
| Specific Gravity | 0.92 | Specific Gravity | 1.25 | Specific Gravity | 0.94 | Specific Gravity | 0.980 |
| Flash Point | 575 F | Flash Point | 347 F | Flash Point | 465 F | Flash Point | ND |
| Softening Point | 226 F | Softening Point | 215 F | Softening Point | 158 F | Softening Point | 164 F |
| Ash Content | 0.003% - .015% | Ash Content | 0.015% | Ash Content | 0.003% - .015% | Ash Content | 0.004% |
| Viscosity 150°F (CPS) | Solid | Viscosity 150°F (CPS) | Solid | Viscosity 150°F (CPS) | 420 - 430 | Viscosity 150°F (CPS) | ND |
| Viscosity 160°F (CPS) | Solid | Viscosity 160°F (CPS) | Solid | Viscosity 160°F (CPS) | 283 - 300 | Viscosity 160°F (CPS) | 810 - 960 |
| Viscosity 170°F (CPS) | Solid | Viscosity 170°F (CPS) | Solid | Viscosity 170°F (CPS) | 227 - 240 | Viscosity 170°F (CPS) | 777 |
| Viscosity 180°F (CPS) | Solid | Viscosity 180°F (CPS) | Solid | Viscosity 180°F (CPS) | 200 | Viscosity 180°F (CPS) | 510 - 635 |
| Viscosity 190°F (CPS) | Solid | Viscosity 190°F (CPS) | Solid | Viscosity 190°F (CPS) | 160 | Viscosity 190°F (CPS) | ND |
| Viscosity 200°F (CPS) | Solid | Viscosity 200°F (CPS) | >10,000 | Viscosity 200°F (CPS) | 130 | Viscosity 200°F (CPS) | 360 |
| Viscosity 220°F (CPS) | Solid | Viscosity 220°F (CPS) | 32.00 | Viscosity 220°F (CPS) | ND | Viscosity 220°F (CPS) | ND |
| Viscosity 230°F (CPS) | Solid | Viscosity 230°F (CPS) | 20.50 | Viscosity 230°F (CPS) | ND | Viscosity 230°F (CPS) | ND |
| Viscosity 240°F (CPS) | 7100.00 | Viscosity 240°F (CPS) | 15.50 | Viscosity 240°F (CPS) | ND | Viscosity 240°F (CPS) | ND |
| Viscosity 250°F (CPS) | 3350.00 | Viscosity 250°F (CPS) | 15.00 | Viscosity 250°F (CPS) | ND | Viscosity 250°F (CPS) | ND |
| Volumetric Expansion 120°F | 2.500% | Volumetric Expansion 120°F | 1.500% | Volumetric Expansion 120°F | 3.4% | Volumetric Expansion 120°F | 3.30% |
| Volumetric Expansion 140°F | 4.300% | Volumetric Expansion 140°F | 2.800% | Volumetric Expansion 140°F | 8.9% | Volumetric Expansion 140°F | 8.60% |
| Volumetric Expansion 160°F | 6.200% | Volumetric Expansion 160°F | 4.200% | Volumetric Expansion 160°F | 10.6% | Volumetric Expansion 160°F | 12.80% |
| Volumetric Expansion 180°F | ND | Volumetric Expansion 180°F | ND | Volumetric Expansion 180°F | ND | Volumetric Expansion 180°F | ND |
| Volumetric Expansion 200°F | ND | Volumetric Expansion 200°F | ND | Volumetric Expansion 200°F | ND | Volumetric Expansion 200°F | ND |

Notes: There seems to be some issue measuring Volumetric Expansion at or above 180 F

While thermal volumetric expansion is a slight factor in causing this heavily included surface when casting carving wax (see Figure 1), it is not the percentage of volumetric expansion that is the main cause of this phenomenon. There are a couple of interactive factors that I believe are causing this defect. The melting temperatures and related viscosities of the wax as it relates to volumetric thermal expansion, combined with the vaporization temperature of water, seem to be the culprits.

Table 4 *Viscosity references*

| Viscosity in centipoise | Consistency similar to |
|--------------------------------|-------------------------------|
| 1 | Water |
| 500 | No. 10 motor oil |
| 2,500 | Pancake syrup |
| 10,000 | Honey |
| 25,000 | Chocolate syrup |
| 50,000 | Ketchup |
| 250,000 | Peanut butter |
| 1,000,000 | Paste-caulking |

As both waxes heat up, they expand at virtually the same percentage rate. The difference is that the injection wax has a lower melting temperature and a much lower viscosity, so it extrudes right out of the gate through the sprue and out of the flasks. The carving wax, however, is expanding in place because the softening point of many of these carving waxes is around 225°F–250°F. This is higher than the 212°F evaporation point of the water in the investment mold. This means that the carving wax expansion creates a slight pressure against the investment mold. The steam that is generated during the burnout is being resisted and trapped between the inner mold surface and the carving wax. The steam pressure at the carving wax/mold interface likely becomes large and static. So the investment breakdown, in this case, is mostly caused by the steam pressure at that interface, and not just the stationary volumetric thermal expansion of the carving wax. It is a condition called “spalling,” but not in the traditional sense. You will notice that (Figure 2), the injection wax gates are smooth and show no evidence of this spalling defect, while all the carving wax hearts are heavily included.

Solutions

Now the most simple solution to this problem is to simply make RTV molds of your carved waxes. If you have 24 hours of curing time available for the mold and a wax injector, you can then make injection wax duplicates of your original carved wax and cast without fear of loss. Sometimes you may have the luxury of time and sometimes you won't. Most of the time, I don't. Another solution is to use a stronger, more durable investment product. You could use a phosphate-bonded investment that is commonly used for platinum alloys, but it is difficult to work with and too slow for typical model demands. There is a newer rapid prototyping investment powder that is now available that is less expensive than the rapid platinum investments, and still allows you to invest and cast your model in 2 to 3 hours with a nice smooth surface. You can also cast platinum in this type of investment and the results are good, but it was designed for rapid prototyping. This type of investment powder is relatively simple to use, requires no binders and is ideal for small batch production. The strength of this type of investment is much greater than gypsum-bonded investments and it can be cast with a flask or flaskless. I would say that the final answer is somewhere between, always making an RTV mold and using this new rapid prototyping investment product.

3D Printing Waxes

These types of waxes don't seem to have the issues with melting temperature and viscosity that carving waxes do. They do tend to have other issues related to model making that need to be addressed. The first issue is the surface finish of many printed models. The higher the resolution of the print of these models, the smoother the surface. The higher the resolution of the print, the longer it takes and the more expensive it becomes. The lower the resolution, the rougher the surface is, but it works. These machines also use multiple jets that spit out tiny drops of wax as they travel along. Sometimes one or more of these jets become clogged. If this happens, you might end up with tiny holes or voids in the surface of your printed wax. Some of the holes may be too small to see in the wax, but often show up later in the cast silver model. Another issue with this type of rapid prototyping material is that this method is used when production on a CNC mill will just not do the job. This type of model typically contains more fragile parts, such as a gallery or some other delicate structure. It won't be so delicate once it is in metal, but in printed wax, it is delicate. I have seen many a delicate printed wax crushed in shipment, just from the shock transferred by the cotton in the small box as it was tossed from the top of a FedEx truck.

These issues can be resolved easily, and it is much simpler to repair the wax or prevent the breakage than to print another 20-hour wax. There is a new UV curing product available that can strengthen the waxes, smooth the surface and fill the tiny holes all at once. Be advised that it needs to be used with a non-visible UVA longwave light source that produces light of the wavelength of at least 365 nanometers. A non-visible light source is basically a black light, but it needs to have the right output. Non-visible light source is important because it is a much cooler UV light source since we are dealing with wax here. This product has been formulated to “wet” the wax and have very little fillet. This means that it doesn’t make your sharp corners too round. I am not sure if it is commercially available yet, but it will be coming soon to a CAD-CAM supplier near you.



Figure 3 Wax pattern with mold defect caused by solder pit in master model

MOLD MAKING DEFECTS

Hubert Schuster will be covering some advanced mold cutting issues at this Symposium and probably some of the related defects that they resolve, so I will only cover this topic lightly. There are the typical defects, such as non-fill waxes due to improper venting and seams caused by improper pressures or a poorly cut mold. Rough wax surfaces that are caused by rough and pitted models continue to cause excessive cleanup and overall, extra production time. As was mentioned earlier, a careless blade can quickly damage a perfectly good model. If this carelessness continues over time, you will have waxes with large scratches in them from subsequent molds that will increase finishing time. As an alternative, you could polish the models, but with too much polishing to remove scratches, your original specs no longer match your production pieces. In the latter case, model repairs can cause nearly every defect imaginable. Don’t forget the collateral damage caused when polishing a model with buffs and brushes. It is

unlikely that, when you are polishing a repaired area, you will only touch that repaired area. Model repairs can change the dynamics of the model by altering the thickness in the affected areas. Assuming that you designed the piece to have proper directional solidification, it may no longer be. This is especially true if the original model becomes so damaged that a new one must be produced. If you do not have an RTV mold of the original, or if you are not using a master/model program, then you could be in serious trouble with your customers. Again, I would like you to consider an alternative metal to cast and fabricate your models.

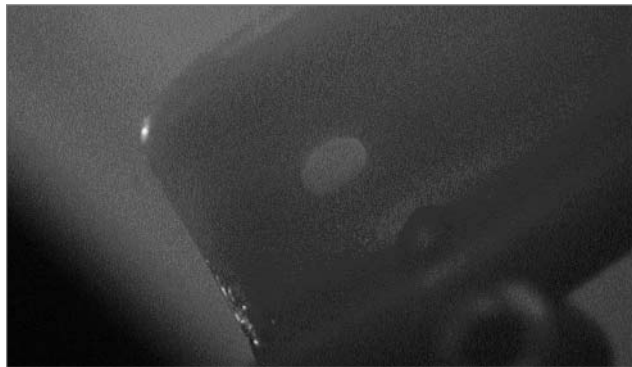


Figure 4 Air bubble trapped in wax pattern

Trapped Air in Molds

In my 2002 paper, I covered the issues of air that was trapped in rubber molds during wax injection or introduced into the wax by various means. Trapped air can come from several sources, but the resultant defect is pretty consistent. Bubbles that are trapped in the waxes (Figure 4) will pop during the investing process. Most often it is due to improper venting of the molds. Improper venting means that the vents available for the air to escape during injection are inadequate for the volume of air in the mold to escape relative to the rate of wax injection. What it can also mean is that the location of the vents relative to the injected wax flow pattern blocks air from escaping during the injection process. Air can also be trapped by turbulence or cavitations of the wax in the mold. For instance, air can be trapped in molds if the wax must flow backwards in a turbulent fashion to fill the pattern. It can swirl and encircle bubbles rather than forcing the air out of the mold through available vents.

Introduced Air in Molds

Introduced air wax defects can also arise from a number of sources. Water in the compressed air lines that feed your wax injectors is a major cause of this defect. The absence or improper use of conditioned air-line dryers or desiccant dryers

will assure this. It sometimes happens that a source of bubbles in your waxes is from dissolved gas in the wax from the manufacturer. Air can also be trapped when new wax chips or dots are loaded into your wax pot. If small air spaces between the cold wax chips are covered over by a molten surface before the air can escape, it is possible for these tiny bubbles to remain trapped until they are injected into the molds.

Automatic Wax Injector Defects

Automatic vacuum wax injectors can produce more consistent waxes in general than waxes shot by hand on conventional wax pots because ideal parameters are easier to repeat. But these same vacuum wax injectors can also help your operators create bubbles in the waxes. Most of these machines draw vacuum through the injection nozzle in order to remove the air from the mold. If you are shooting a mold designed for traditional wax injection pots—one that is vented and powdered, for example—the vacuum injector simply draws in air through the vents. If this is the case, some air can be drawn through small amounts of molten wax in the injection nozzle. Bubbles are trapped in that wax and are then injected into the molds with no chance of escaping.

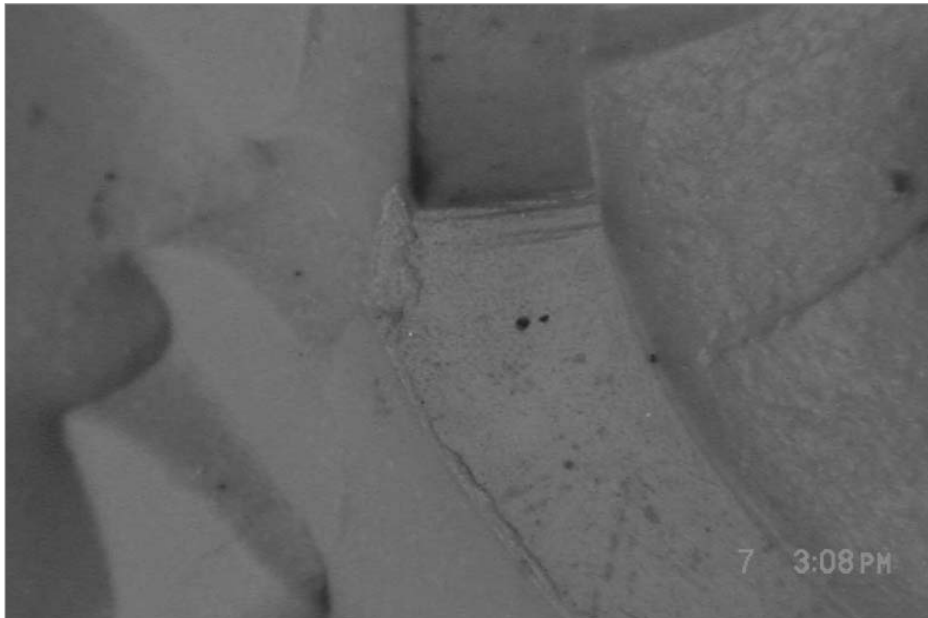


Figure 5 Accumulation of powder and mold spray in a mold

Dirty Molds

Mold-related defects could also be caused by improperly maintained (dirty) molds. As was discussed in 2002, the improper application of powder and/or

silicon mold-release spray can cause rough casting surfaces and non-fills. Silicon sprays are used as lubricants or mold-release agents to facilitate easy, distortion-free removal of the wax from the rubber mold cavity. Powder is used to create a microscopic path for the air in the mold to escape through the air vents during the injection process. Never should these two materials meet each other in the rubber mold cavity. Powder of any kind that has absorbed a wet-spray lubricant or other liquid will make a positive formation in the mold (see Figure 5). This positive formation will translate to a negative formation in the surface of the resulting wax (Figure 6). This will appear as a negative in the casting (Figure 7) and require repair or recasting. Without training and experience, this defect is hard to tell from investment inclusions. The repair remains the same, but the more important issue of prevention can be lost.



Figure 6 *Rough surface on wax pattern from dirty mold*



Figure 7 *Casting from defective wax pattern still shows rough surface*

Powder Problems

Powder and spray must be used correctly for best results. Ideally, the powder used to allow air to escape the mold is very fine and organic (burnable), such as cornstarch or rice flour. It must be applied specifically to the areas that need it using a small brush. It is ill advised to apply any powder to the mold indiscriminately by powder socks or hammers. Many companies still use talcum powder, which is a mineral and does not burn. If this mineral gets in or on the waxes that are used to create the investment mold, the talc remains in the mold cavity after burnout. When the molten metal is introduced into the mold cavity, the talc floats on the molten metal stream because of its density. This floating material, just like mini investment inclusion, creates rough surfaces that must be dealt with later in the production process.

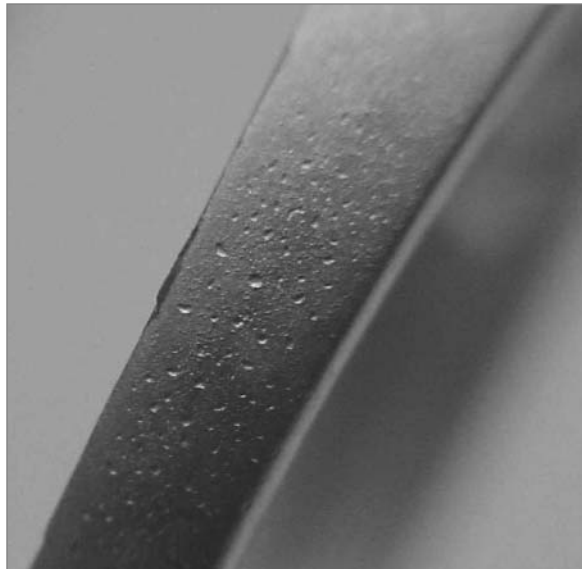


Figure 8 Defect caused by mold release liquid preventing the wax from reaching the mold surface

Mold Release Spray Issues

The misuse of silicon mold release spray can also produce surface defects. Injecting wax into the mold cavity before the mold release spray has had time to dry causes a unique defect. As wax is injected into the mold, the wax fills over the droplets. Because two bodies of mass cannot occupy the same space at the same time, the non-miscible droplets form smooth, rounded, irregular-shaped negative spaces in the casting surface (see Figure 8). I have seen this defect incorrectly identified as porosity several times.

Keep it Clean

If you and your factory are already guilty of the above infractions, besides a sound whack on the hand for you, have your workers pick a day and do a thorough cleaning of your current mold inventory. Use a good short-bristled brush and some simple dishwashing soap to clean the gunk out of your molds. Dry them with compressed air, especially in the vents. Now powder your vents only, blow out the excess with compressed air, let the tension off the molds, and lubricate sparingly with your fine-mist mold lubricating spray.

TREE-BUILDING DEFECTS

The shape and care that you take in building a wax tree can have significant effects on your casting defects. In my 2002 SFS presentation, most of the discussion presented about tree geometry was related to costs savings and mathematics. In this discussion, I want to relate this primarily to defect reduction. There are two main ways in which your tree building personnel can help or hurt you: the way they attach the waxes to the trees and the overall tree geometry.

Gate Sprue Interface

The way gates are attached to the sprue can cause investment inclusions. The junction of the gate and the sprue must have a smooth rounded transition. The common practice of melting a hole in the sprue and sticking the gate in the molten wax is not ideal. This method causes sharp spaces above and below the gate as is pictured in Figure 9.



Figure 9 Gate/sprue interface 1

These sharp spaces become sharp investment pieces that protrude into the mold cavity. At the time of casting they are hot, thin, fragile investment points that break off as the molten metal enters the flasks (Figures 10 and 11). These broken points are carried down and out into the castings by the molten metal. These small pieces of investment float on the molten metal and are nearly always

found on or near the surface of the casting, and usually, more often on the side of the casting facing up towards the button. This is one method to help determine the root cause of investment inclusions. Spalling typically has positive metal defects all over the casting that accompany negative defects towards the button. Inclusions from poor practices normally only have negatives on the button side of the casting.

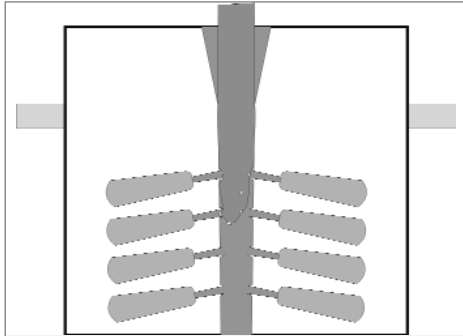


Figure 10 Gate/sprue interface 2

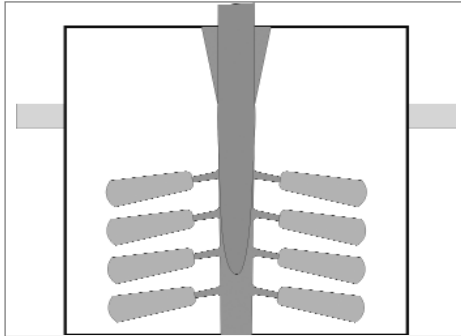


Figure 11 Gate/sprue interface 3

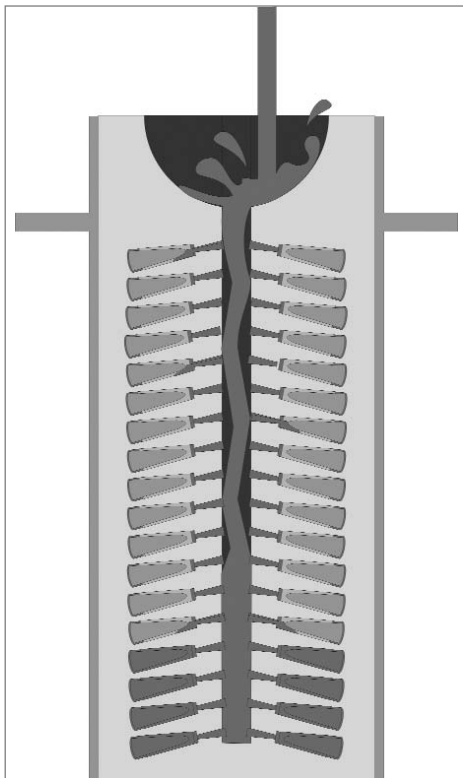


Figure 12

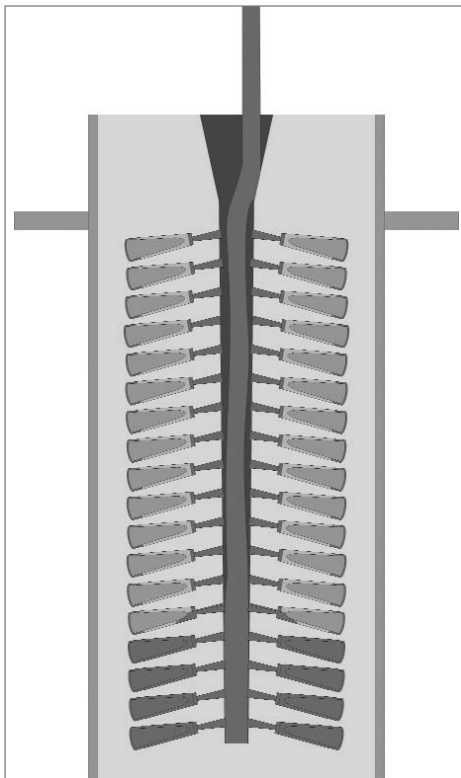


Figure 13

Random Non-fills

Reducing these defects is certainly related to costs savings, but so are all defect reduction actions. Random non-fills are defects that are directly related to tree and equipment geometry. The shape of the button, the positioning of the flasks relative to the pour hole in your casting machine, and the angle of the gates to the sprue are all equally important to successful casting. As you can see by the illustrations, the old C-type sprue base (Figure 12) more times than not causes your metal to bounce from side to side as it travels down the sprue. As it bounces, it often deposits small bits of metal in the gates and part cavities of the investment mold. Since the metal fills from the bottom of the flask up, the bits of deposited metal have time to cool a little. This often forms plugs in the gates that don't allow the metal to fill the part when the time comes. Ideally you want the metal to have the smoothest, straightest path possible when entering the mold cavity (Figure 13).

Since the metal only fills from the bottom of the flask toward the top, the common practice of using extreme angles for the parts on the tree does little more than waste space and, again, helps create a situation to enhance non-fill defects. Using a conical button-shape and tapered sprue, when the parts are at an 80–90 degree angle, liquid pressure, inertia and cohesion are all that is necessary for the molten metal stream to fill properly. Vacuum casters that believe, or actually get good fill rates with trees at extreme angles, are likely casting at higher than necessary temperatures. This means they are using higher flask and metal temperatures than necessary to compensate for these practices.

INVESTING AND DEWAX DEFECTS

Assuming that your investment powder is good quality and stored properly, the three main factors that make or break your investing process are time, temperature and water quality. I have, on very rare occasions, run into defects caused by actual issues with investment chemistry.



Figure 14 Water marks

Many times I have worked with companies that were really proud of the fact they could get through with their investing faster than the investment manufacturer suggested. A very common mistake happens when the investing process work time is shortened. Watermarks (snail trails) often appear as a result. If you shorten the “work” time of the investing process, the water can separate from the investment slurry. Because the water is lighter than the slurry, this separated water will form rivulets that start making their way up to the top of the flasks. As these rivulets travel upward, they contact your waxes on the underside and take the path of least resistance on their continued upward path, as is pictured on the bracelet shown in Figure 14. The water rivulet path leaves a trail of weak investment with a higher water-to-powder ratio than is supposed to be there. Often, this weak investment drops into the mold cavity during burnout, or is washed out by the molten metal during the casting process. You now have the positive defect known as snail trails and the additional negative defects and rough surfaces caused by the free floating investment particles. Water quality is far more important than most people realize. At the *2000 Santa Fe Symposium*, Ralph Carter, the materials engineer for Ranson and Randolph gave a great paper on this subject. In a nutshell, his paper stated that while many common tap water contaminants didn’t have a drastic effect on phosphate-bonded investment set-up times, in some cases, the set-up times for gypsum-bonded investments, were greatly affected. Small DI water units are available from many jewelry tool supply houses and are quite affordable, or they can also be rented from companies like Culligan. They are far more affordable than the extra work time you can experience without them.



Figure 15

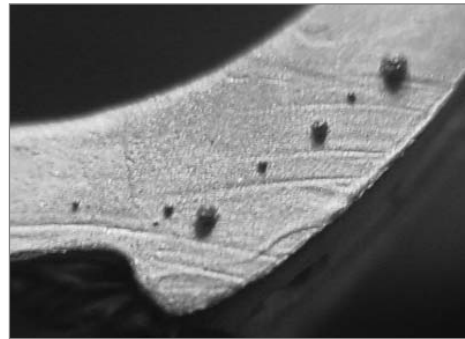


Figure 16

Air bubbles trapped in the investment

The second most common investing defect is caused by poor maintenance of the vacuum machine pump, gaskets, hoses or hose clamps. The result of this poor maintenance is metal bubbles on your castings as pictured in Figures 15 and 16. (There is an interesting slang name for this defect and you can ask me later). Since I also went into fairly good detail on this subject at the *2002 Symposium*, I won't bore you with a repeat. Suffice to say that regularly scheduled maintenance on your equipment is essential. That your vacuum gauge reads the required vacuum level doesn't necessarily mean that you are pulling the full vacuum in the vacuum chamber. A good way to check this is to put a container of water inside the vacuum chamber when you first get your machine, or when you are sure that a good servicing has been completed. Measure the amount of time it takes to get the water in the container to boil vigorously. Write this information right on the machine so that it does not get lost. Later, if you start seeing these metal nodules, you can compare the time it takes the water to boil in the vacuum chamber using ideal baseline numbers.



Figure 17 Investment defect from steam dewaxing with water level too high

STEAM DEWAX DEFECTS

I had heard of and seen defects that were classified and trailed back to the steam dewax units in many factories. I had known that when you saw what appeared to be spalling at the end of the tree towards the button, dewaxing for too long a time was the likely culprit. On a fairly recent consulting trip, I saw a new twist to this defect. This defect (Figure 17) was appearing regularly. Time after time, I questioned, reviewed the records, and finally timed the dewax process myself. The defect still appeared with all known parameters being well within guidelines. When all “known parameters” are within guidelines and there is still a problem, then there is an unknown factor.

Just before I lost my mind, I came upon the obvious, but so far “unknown” answer. It was not a factor of time that was causing the problem. It was proximity to the water under the grate where the flasks were resting that was the factor. These particular dewax units had a wire mesh grate system that, over time and use with 14, 4" x 9" flask loads, had begun to sag. Also, the water level in these particular dewax units was manually filled and not automatically filled using a float. These two things put the opening of the flask right on top of the

water level. As the water in the dewax units began to boil, the wax was quickly eliminated from the bottom, allowing the boiling water and steam to erode the lower portion of the mold cavity. We fixed this by making some new, stronger, barbecue grill-like grates to fit into the de-waxers. We also made a tool to indicate the proper water level in the de-wax units. I didn't have time to make auto-fill units, but I wish that I could have. Maybe you should take a look at this if you steam dewax. You can tell the difference between this defect and spalling caused by a too-rapid ramp in the burnout process, because that defect is more generally located as compared to this erosion that occurred at the bottom of the flasks.


BURNOUT SCHEDULE DEFECTS

Using the proper burnout schedules and ramping rates for the task at hand is essential. After your 3-hour initial dwell time, a generally prescribed rate of 4 degrees per minute ramp time is best to ensure good quality cast surface. This rate should allow any residual water to be dissipated without causing damage to the mold cavity surface or cracking in the investment. Your top temperature depends on the type of casting you are doing, but for most non-stone containing jewelry flasks, it is 732°C/1350°F.



Figure 18

The temperature of the investment inside the flasks will not exceed the boiling point of water (100°C/212°F), as long as it contains water. If you are trying to force the burnout to go faster by ramping up the temperature too fast, stop it! What will happen is that the pressure of the escaping steam will increase to a level that will cause erosion of the mold cavity (see Figure 18). Chips and flakes will pop off from the interior mold surface into the cavity and cause your castings to be rough and included. The issue with the carving wax in the previous section was slightly different because it is not affected as much by the temperature of the steam during this stage of the process.



Another issue in this section is that the hold time at the top and final temperature of your burnout schedule should be the time that your flasks reach temperature, and not the time that your oven reaches temperature. By using an imbedded thermocouple in a dummy flask with a dual pen chart, you will more accurately know what is occurring in your flasks. Because of the air/fuel mix of your oven, the number of flasks in the oven, or the conditions at your facility (high elevation, lower oxygen levels), you may need to modify your parameter to ensure maximum product quality.

STERLING SILVER ALLOY ISSUES

There has been a lot of press over the past years regarding gold alloys and gold production issues. It is my opinion that casting high-quality gold products is, on the whole, easier than casting high-quality sterling silver products. The same laws of physics, chemistry and mathematics apply regardless of the alloy your casting. In sterling alloys, you only have 75 parts-per-thousand to impart all of the requirements of the retailers and manufacturers into the alloy. Most manufacturers want to purchase all of these properties from the alloy suppliers in the alloy only form. The manufacturers want to use their own pure silver sources because they need to save on the shipping costs associated with the movement of the complete sterling alloy. This becomes a huge issue when it comes to the newer, tarnish-resistant sterling alloys that are now demanded by so many retailers. The components of these alloys compete for space in the alloy matrix and, if not done properly, cause their own special types of defects. So the trick is to get all these components in the right proportion into 75 parts-per-thousand of the total alloy and still impart the desired sustainable qualities. This is quite a tall order for the alloy manufacturers. It seems to have happened in many commercially available sterling alloys with varying degrees of success.

The alloy manufacturers can't factor into their equations things like the oxygen content of the .999 Ag from the various sources. This can range anywhere from 20ppm all the way up to 400ppm in extreme cases. Even in .999 Ag there are contaminants that often come from the original use before refining, like sulfur from the film manufacturing and reclaiming industry. Other things they can't factor in are the use of oxygen scavenging elements like phosphorus and lithium that some refiners use to improve their products. Typically, the refiners who use these elements use a standard amount rather than test for oxygen. Oxygen tests are not easy and must be performed in precisely controlled conditions in a good lab. If there was more than enough of the scavenging element, some may remain, which can lead to certain specific defects.

Oxygen in .999 Ag is something that most casters who alloy their own sterling don't think about much. The equilibrium diagram for silver and oxygen (Diagram 1) shows that in the molten state, Ag and O₂ love to cohabitate. While Ag₂O does not exist above about 190°F, molten Ag can absorb about 10 times its volume in oxygen. In the solid state it can absorb virtually none.

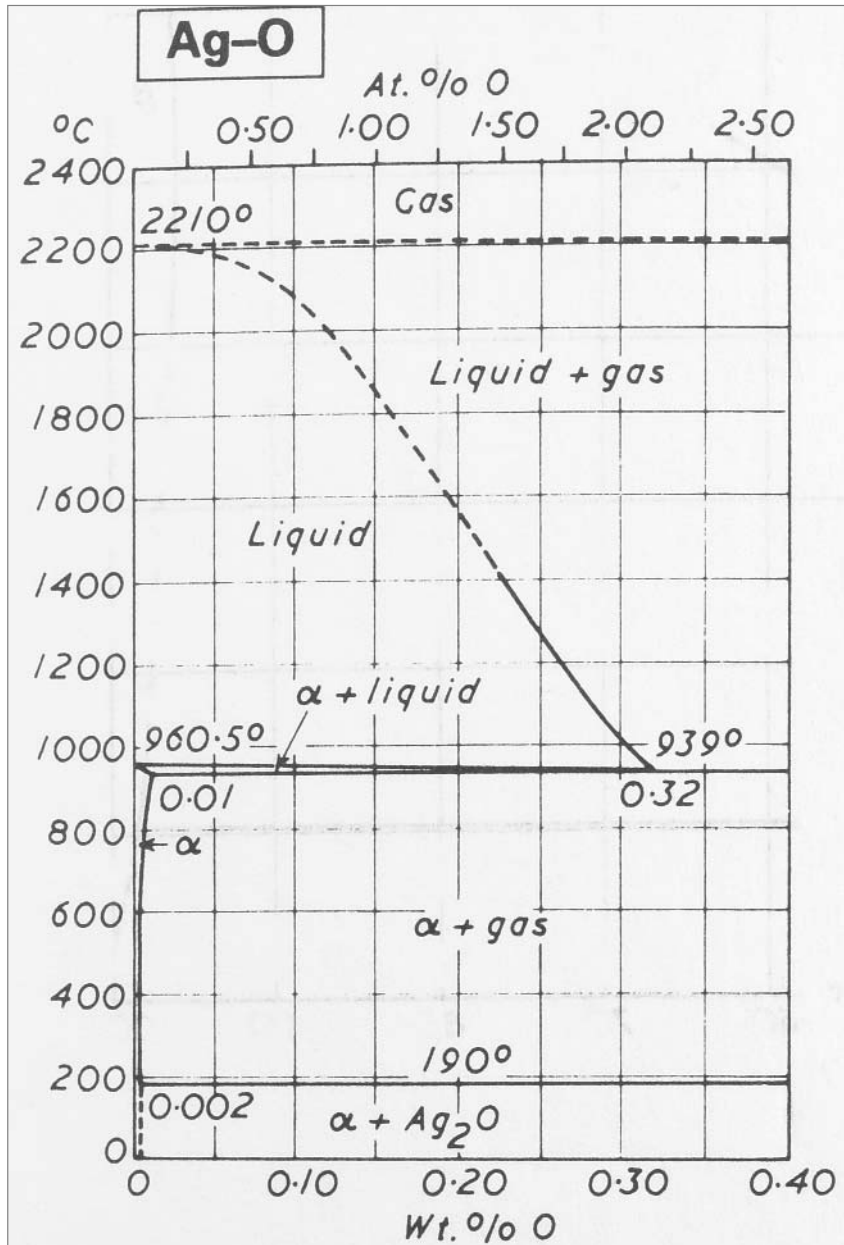


Diagram 1 Ag-O equilibrium diagram

Table 5 (courtesy of NSL Analytical Services Inc., Cleveland, OH)

| | | .999 Ag trace elements testing | | |
|--------------------------------|-------------------|---------------------------------------|-----------------|-----------------|
| | | Sample A | Sample B | Sample C |
| Ag | Difference | 99.9000% | 99.9000% | 99.9000% |
| P | Mass Spec | <0.0050% | <0.0050% | <0.0050% |
| Se | Mass Spec | <0.0010% | <0.0010% | <0.0010% |
| S | Leco | 0.0010% | 0.0010% | 0.0010% |
| Pb | Mass Spec | 0.0014% | 0.0014% | 0.0002% |
| Li | Mass Spec | <0.0001% | <0.0001% | <0.0001% |
| Dissolved O₂ | Leco | 0.0280% | 0.0300% | 0.0140% |

There are two issues here to consider. Even though silver cannot absorb oxygen in the solid state, it can contain oxygen in solid state. Look at the table of analysis of the three .999 Ag samples from different sources (Table 5) that were done by NSL Analytical. What can happen in these two situations of dissolved gas in solid Ag and absorbed O₂ in Ag is when the alloying elements are added, there is already oxygen available to react with the sacrificial elements that are in the alloys. In a standard Ag-Cu alloy, you will get one or both forms of copper oxide. One is cuprous oxide (Cu₂O), which is easily reduced by using a carbon crucible or charcoal on the melt. The other is cupric oxide (CuO, firestain), which is formed with continuous exposure of oxygen to Cu₂O. (Ref. 1990 SFS Carrano). In the newer alloys that are designed to be tarnish-resistant, the sacrificial elements are there to protect the copper from oxygen. That is why I hesitate to call them “De-ox” alloys. The elements like Si, Zn and Ge are there to react with the oxygen first, before it gets to the Cu. For any of you who cast using these types of alloys, you will recognize the slag that forms in your crucibles. So there are oxides being formed that cause types of casting defects, it just isn't the copper that is being oxidized.

Table 6 De-ox alloy change

| | Process | | | | | | | | | | | |
|--------------|----------------|---------|--------|--------|-------|-------|-------|-------|--------|-------|-------|-------|
| Description | Steps | Ag | Cu | Zn | Sn | In | Fe | Si | O | B | Al | S |
| .999 Ag | 0 | 99.9984 | | | | | | | 0.0016 | | | |
| Deox alloy A | Alloy shotting | 955.200 | 32.500 | 11.100 | 0.460 | 0.420 | 0.130 | 0.100 | 0.037 | 0.011 | 0.010 | 0.002 |
| Deox alloy A | after 1st cast | 959.133 | 31.000 | 9.800 | 0.000 | 0.000 | 0.000 | 0.054 | 0.013 | 0.000 | 0.000 | 0.000 |
| Deox alloy A | After Reshot | 961.464 | 29.600 | 8.800 | 0.000 | 0.000 | 0.000 | 0.120 | 0.016 | 0.000 | 0.000 | 0.000 |

In Table 6, you can see the .999 Ag shot contained small amounts of oxygen before we started. We made the shot and cast, using a carbon crucible in a nitrogen atmosphere. The results from this test indicated to me that while the

.999 Ag contained oxygen from the start, the alloy that was used contained oxygen or oxides already from its own manufacturing process. The oxides that were introduced along with the alloy during the original sterling alloying process were reduced during subsequent processing, as was the Zn and Si. Silicon seems to be a hard element to accurately measure for some labs that are not familiar with jewelry alloys. I say this because the last Si number in Table 6 (after reshot) is higher than the one before it. I don't believe that number and I can't explain it; I am just reporting it as it came to me. This particular analysis was done in early 1999 by another lab. Since that time, I have had the slag analyzed from operations casting tarnish-resistant sterling alloys and, in every case, the slag contained high percentages of Si, Zn and other de-ox elements proportionately.

Random Oxide Related Porosity

As I reported last year, these oxides can form fences in the molten metal stream that can cause shrinkage porosity in areas that theoretically should not experience that defect, according to mathematical models. Like branches under a bridge during a flood, they can create a dam that cuts off the feed of molten metal to an area in a random fashion, causing random shrinkage porosity.

Cracking and De-ox

What I call de-ox elements are things like phosphorus and lithium, both used to remove oxygen from .999 Ag before the alloying begins. These are great elements if used in the right place, in the right amount and at the right time. If not, they can create their own issues. Many silver refiners use phosphorus to de-ox their .999 Ag shot. This is just fine for wrought material production. It only takes a little too much to leave trace amounts that can cause cracking defects in nearly all sterling silver castings. Sulfur is another contaminant that causes cracking in sterling alloys. This is often found in silver that comes from photography industry refining. Of course, there are a myriad of things that can cause cracking in sterling alloys, but that is just one of them. Another thing that can cause cracking in just about any alloy is simple geometry. If your gate is too short, the residual heat from the main sprue can cause cracking next to the gate/part interface.

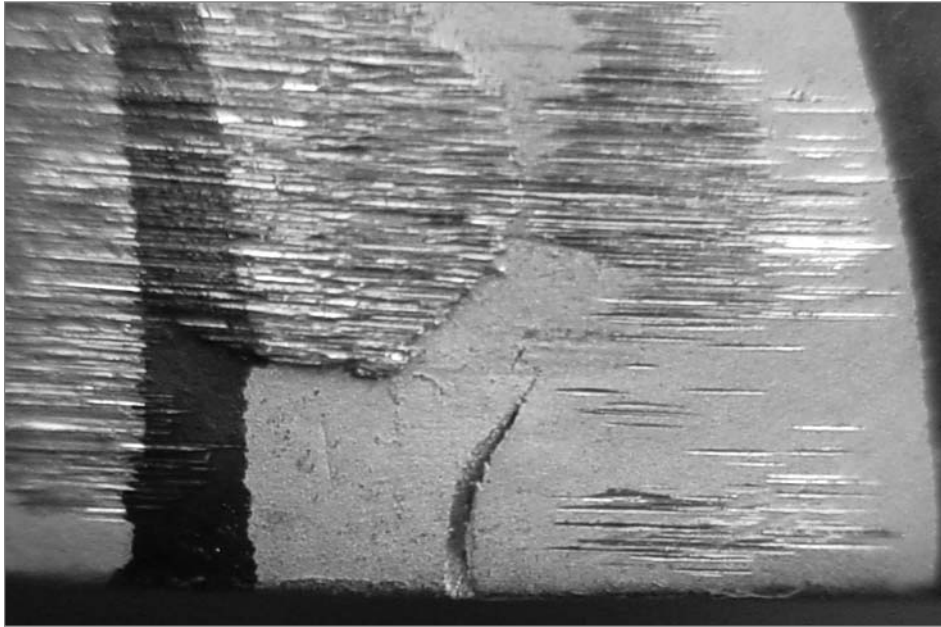


Figure 19 Cracked shank

This defect (Figure 19) is called “hot tear.” If the gate is too large, it can cause the same thing, as well as porosity on the inside of the shank. Even if your gate length is correct but your angle is not, you can get hot tear simply because your angle is too steep, as depicted in Figure 20. This geometry still allows proximity heat from the center sprue to cause the “hot tear” defect. Combine this with phosphorus or sulfur contamination in your silver, and you really have cracking problems.

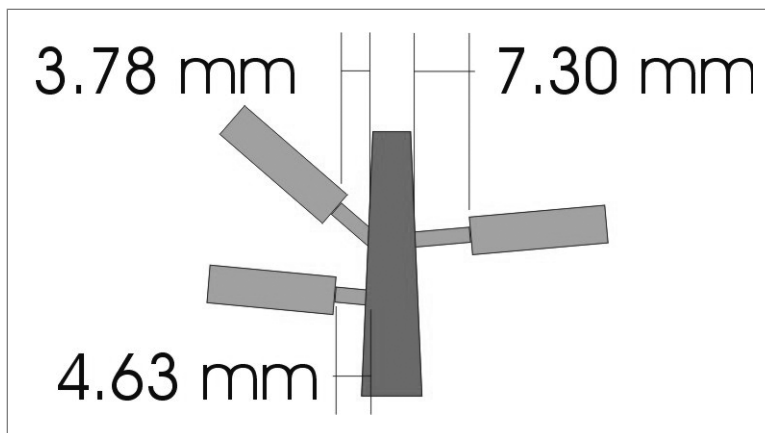


Figure 20 Gate geometry

A new defect came up recently that seemed to be related to the use of lithium. Lithium is another element that is used (much less frequently) to de-ox .999 Ag. It is so reactive that it is tricky to get it down into the melt so it can do its thing. I was recently involved in helping to discover the source of a defect that seemed unexplainable. In order to help prevent defects related to dissolved oxygen in their sterling silver manufacturing, this company was pre-treating their .999 Ag with an amount of lithium right before adding their alloy to the molten silver. Just to make sure they got all the oxygen out, they started increasing the amount of lithium they added. Over time, they started seeing defects that they had never seen before. They started seeing what appeared to be small explosions on the surface of their castings. These explosions had a light gray appearance around the hole in a tarnish-resistant sterling silver alloy. I knew their alloy and I knew their process, so I did my best to work out and balance an equation that took into account as many elements that I could think of. I will not include this equation for fear of some real chemist having a coronary while laughing their head off. My conclusion at the time was, that if there was residual lithium in the alloy, it might be possible in a real world investment decomposition reaction, that there would be oxygen available for the residual lithium to cause these small explosions. Whether I was right or wrong, I'm not sure. What I am sure about is that reducing the amount of lithium to a much lower original number caused the problem to go away. I would like to research this and other similar issues further if I can find funding.

More Explosions

Other reasons for abrupt gas defects might be related to plain old H₂O. This will be of particular interest to you folks who like (H₂N₂) forming gas. As was reported at the 1987 and 1989 *Santa Fe Symposium* by Dr. Chris Raub, hydrogen diffuses into silver quite readily. He indicated that if you have copper oxide present, the hydrogen will then reduce the copper oxide and form H₂O (steam). This steam could cause blisters, or it could blow the surface off of rolled material that looks like a plated layer has been lifted off the surface. In both of these papers, this defect was discussed in relationship to wrought product that was later annealed in a reducing hydrogen atmosphere to form the defects.



Figure 21



Figure 22



Figure 23



Figure 24

Two different tarnish resistant castings of the same alloy



Figure 25



Figure 26

It could be that the flask was just cast too hot and these defects were caused by extreme SO_2 liberation, but I was told that these flasks were cast using about 950°F (510°C) flask temperature and a 1765°F (965°C) metal temperature. Those temperatures are well within reason. If this is true, then I am starting to think that this hydrogen defect may also exist in cast product as well. I wonder if it was possible for the hydrogen to be in the Ag and the oxygen came from

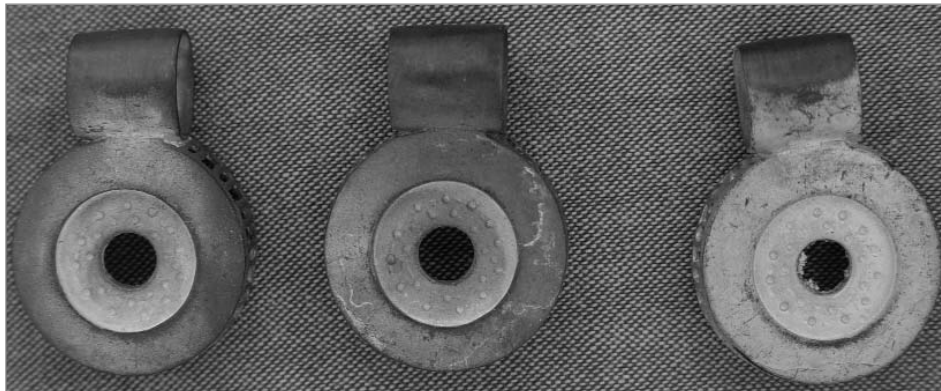
the decomposition of the CaSO_4 -bonded investment. If the silver shot were pre-treated with something like lithium to remove O_2 , then shot and cast using forming gas, why wouldn't the .999 Ag absorb H_2 ? I don't think that there would be anything present there to stop it. I am suggesting this because, as you can see in Figures 21–24, the eruption on the rings happened on the opposite side of the gate connection to the rings. This junction was the hottest spot during the cooling of the ring and would have cooled last. It took a second or so for the oxygen in the form of SO_2 to liberate itself from the investment. Hydrogen is more reactive than sulfur, so wouldn't that replace the S in SO_2 to form $2\text{H}_2\text{O}$? As Chris Raub discussed in 1987 and 1989, it formed water vapor that literally blew the surface off the casting, looking like someone pried up a plating layer. The larger defects in the sprue (Figure 25) and button (Figure 26) could have been larger examples of the same defect. The hydrogen was pushed out of the Ag as the metal cooled. Remember, the "de-ox" agents in the sterling are there for the oxygen, not the hydrogen. So I feel that the timing of the decomposition of the investment and the location of still molten metal if H_2 was available, could all have played a role in the defects pictured above. Wherever the O_2 came from, if there was H_2 available, it would be more reactive and would combine with the O_2 . Maybe I'm all wet on this, no pun intended, but I feel that further research is warranted because this was a very fun defect. Of course I was not the caster or the customer, so the fun was relative.

Table 7 Three .925 Ag alloys
(courtesy of NSL Analytical Services Inc., Cleveland, OH)

| Sterling Silver Alloy Test | Sample SS A (ring) | Sample SS B (ring) | Sample SS C (ring) |
|-----------------------------------|---------------------------|---------------------------|---------------------------|
| Ag | 92.790% | 92.780% | 91.170% |
| B | <0.001% | <0.001% | <0.001% |
| Cu | 4.140% | 2.090% | 1.770% |
| Ga | <0.001% | <0.001% | <0.001% |
| Ge | 0.001% | 0.002% | 0.310% |
| In | 0.050% | 0.008% | 0.200% |
| Ni | 0.002% | <0.001% | 0.001% |
| O | <0.001% | 0.005% | 0.010% |
| P | <0.005% | <0.005% | <0.005% |
| Sb | <0.001% | 0.005% | <0.001% |
| Si | 0.140% | 0.170% | 0.039% |
| Sn | 0.160% | 0.033% | 2.610% |
| Zn | 2.230% | 4.550% | 3.450% |

Tarnish-Resistant Sterling Elements

Combinations of different elements in a tarnish-resistant alloy not only give variable degrees of tarnish resistance, they also impart different mechanical properties, as you can see in Figure 27. These as-cast pendant samples were immersed at the same time in a 15-second bath of 150°F liver of sulfur and then rinsed. This is a pretty harsh environment, but I just wanted to show that there are differences.



Alloy SS-A

Alloy SS-B

Alloy SS-C

Figure 27

The next three pictures (Figures 28–30) are the same three different alloys in the same order. I tested them as a manufacturer might by putting them on a Kagen ring stretcher and pushing them to their limit. Many jewelers try to size sterling rings by hammering rather than cutting and adding pieces. All these rings started at size 8.75. You can see that alloy SS-A had a large grain boundary and developed an orange peel look as it was deformed, but it stretched to a size 12 before it failed. Alloy SS-B broke sooner than SS-A at about size 11.5 and had a smaller grain structure, but the surface still exhibits some orange peel look. Alloy SS-C made it to a little over size 11.75 before it failed, and appears to have the best grain structure. I don't have any tensile, hardness or elongation test results, but two of these alloys are commercial alloys that are currently in use. I made up the other one based on numerous alloy experiments that I had previously done with some help from a friend of mine in the alloy business, Bruce Pinsof. The numbers in Table 7 are processed alloy numbers. Knowing these numbers and being able to make the alloy is not as easy as it sounds. You have to know what to mix, how, and when to make a good alloy. This is a case where I would like to say don't try this at home. This was done by trained professionals wearing protective gear.



Figure 28 Alloy SS-A



Figure 29 Alloy SS-B



Figure 30 Alloy SS-C

Well, I think this is enough about defects for this paper. My tendency is to keep on writing and talking. There are a lot more defects that are particular to sterling alloys and especially to the newer tarnish-resistant alloys. I have offered some controversial ideas on a couple of defects and I look forward to someone coming along to shoot them down. It won't hurt my feelings and I'll get to learn something else as a result.

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