Metal Flow Optimizing - An Important Step To Successful Casting

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ABSTRACT

Art and jewelry castings have been done more or less successful for well over 5,000 years. To this day, the seemingly simple technique of casting metal has kept its mysteries and degree of difficulty. The reason for this is a number of variables and sometimes-unattended parameters. One of these important parameters is the flow characteristic of the metal, as it enters the mould through the gating system. How does the flow of metal influences a good casting? How can it be modified? These questions, the answers and the systematic exploration of these influence parameters will be the topic of this paper.

KEYWORDS

Art, casting, jewelry, parameters, flow, influence, variables.

INTRODUCTION

During my many years as consultant and advisor to casters in the jewelry industry, I come to realize how few casters actually understand the complex physical interactions that make a casting successful. Mostly only four parameters are deemed important: Alloy composition, investment, flask temperature and casting temperature. Metal flow, a parameter of equal importance is mostly all but overlooked. The advantages use of metal flow and the physical laws regulating them, will contribute to a better casting result. It is the goal of this paper to point out how all these parameters interact.

EXPECTATIONS OF A JEWELRY CASTING

Jewelry and artistic castings have been done for over 5000 years. Casting is one of the oldest manufacturing methods all together. The oldest preserved cast objects are weapons and cult objects made of copper and originate from Asia and India. The finds prove that already in ancient times artisans mastered a variety of form techniques. Models were made from wood, clay and other materials. So called "Lost" forms were made of clay, more permanent ones were made of sand stone, slate or soap stone and even bronze.

Figure 1 shows 3000 year old sand stone form for jewelry. You can clearly see the vents on the side that is designed to carry the air out during the casting process.

figure 1: left side, 3000 years old sand stone form - right side, nowadays usual casting tree

The casting set-up is not much different from the modern casting tree. Casting cone, center sprue and sprues are definitely similar. Castings found are telling of a great skill by the ancient caster especially considering that these have been done without an understanding of the physical and chemical basics of casting techniques.

The reason casting is the most common manufacturing method even today, is based on the many advantages this method offers. One being that jewelry alloys can be cast with great accuracy and very little surface roughness. Even pieces with small cross sections and fine detail as well as massive pieces in many shape varieties can be cast in an economic fashion in small or large runs.

Other competing manufacturing methods are machining and die striking. Recently, electro forming as well as powder technology has been added as competing manufacturing methods.

For casting to stay competitive in times of high financial pressures, it is important to reduce the failure quotient and improve the success rate of castings by affordable means.

There were advances in the area of difficult casting metals for jewelry making. Metals with a high melting points, such as platinum, titanium and stainless steel. Even there, castings with very good quality results are possible. As simple as it may sound, the banality of the process leads to underestimation of its complexity and that can lead to failure. To melt metal, pour it into a pre-heated form, and voila, done. What looks so very simple is recognized by the experienced caster as a complex and tricky technique, with many influencing parameters. How many factors can influence a casting is depicted in the next picture.

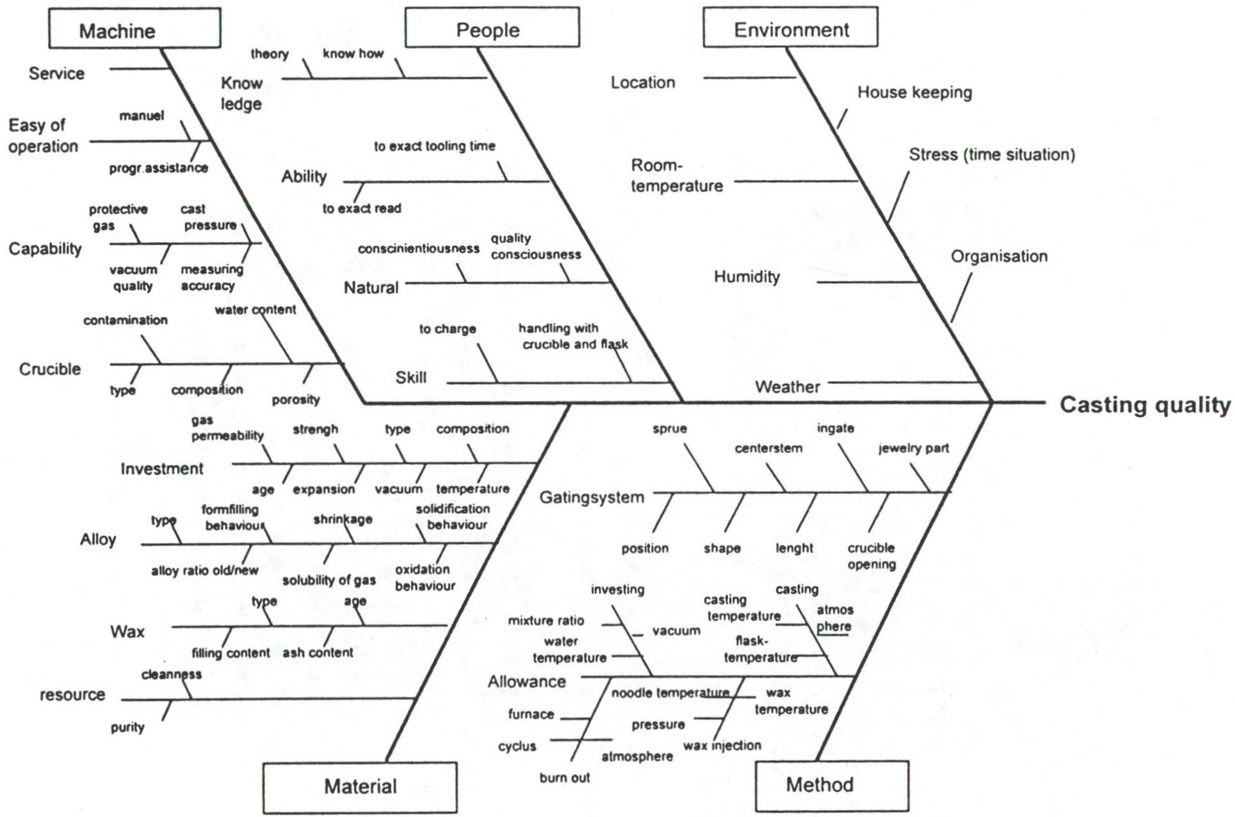


Figure 2: Ishikawa diagram

The number of influence parameters makes it clear that casting is not as easy as it looks. The chance to produce a defective casting is relatively high.

One of the most common casting defects is porosity. It can create high additional cost to repair a casting. If porosity is found immediately after casting, the cost is limited to a replacement casting. However, many times porosity is hidden under the casting skin and is not visible until the final inspection, resulting in much wasted labor cost. Especially bad is the so-called "micro-porosity". This defect is very small microscopic pores that are not visible to the human eye. After the jewelry is in stock for a while, or on display in the window, micro porosity shows up as spots. Spots are hydroscopic, that means moisture from the air, galvanic baths, human skin etc. will be absorbed and stains the metal surface.

Highest priority should be to prevent such defects, but that is only possible if it is recognized as such.

Many casters and jewelry manufactures have the goal to cast porous free. This is wishful thinking and has no bases in reality.
The fact that one cannot cast porous free is in part caused by the shrinkage that occurs as the metal freezes. It can be 4 - 7% of volume. To have a porous free casting, the freezing must take place on a linear plane and that is just not possible. Because of the complexity of jewelry pieces, as well as the entire casting tree, a freezing without enclaves is not possible. With dentritic freezing, a dense filling is especially complicated and is mainly responsible for micro porosity.

This is no reason to despair. Of a decorative piece of jewelry can be said that only what you see is bad. Internal porosity, which does not break the surface, does not reduce the quality of a piece. The same can be said for porosity in the casting skin, as it will be ground and polished away.

Advances to casting techniques are made often. Specifically the development of the casting machines has brought about many inventions designed to help the caster. With modern casting machines, parameters such as casting temperature, atmosphere, pressure and such are no longer coincidences and can be controlled. Still, in spite of all modern aids, the best casting machine is only as good as the operator. The best machine cannot make up missing background information and the lack of understanding of the casting process. The caster is the deciding factor.

To optimize casting success an understanding of cause and effect of the casting process as well as process control and observation of the casting result are mandatory.

In the Ishikawa diagram (fig. 2) we were introduced to many influence parameters, many of which are directly responsible for porosity. Others are responsible for surface quality, accuracy etc.
One influence parameter, which is almost always responsible for porosity is the behavior of the metal as it enters the flask. This is a good reason to examine this point closer.

INFLUENCE PARMETER: METAL FLOW

After the metal has been melted it is deposited into the flask to make the casting. This can be done in several ways. In a centrifugal casting, the metal is thrown into the form by high centrifugal force. In a vacuum/pressure caster, the melt will be cast with a lot less pressure and is sucked into the flask.

From the time the metal leaves the crucible and fills the cavity that make up the castings, a very short time has passed. The metal streams into the casting and sprueing system and that can be the cause of lots of turbulence. This turbulence is responsible for absorption of gas, air enclosures, oxidation, erosion of the investment as well as the forming of so called "hot-spots". These are recognized casting problems. To prevent them, one must understand and recognize the cause. Only knowledge of the cause and result gives us the ability to introduce preventing measures.

If castings are repeatedly bad, most casters begin with temperature variation. If this does not fix the problem, the sprueing system is examined. The caster knows by experience, that a change in the sprue, a different placement on the casting tree or a change in sprue diameter will markedly influence the casting quality. The number of option for re-spruing are demonstrated in fig 3.

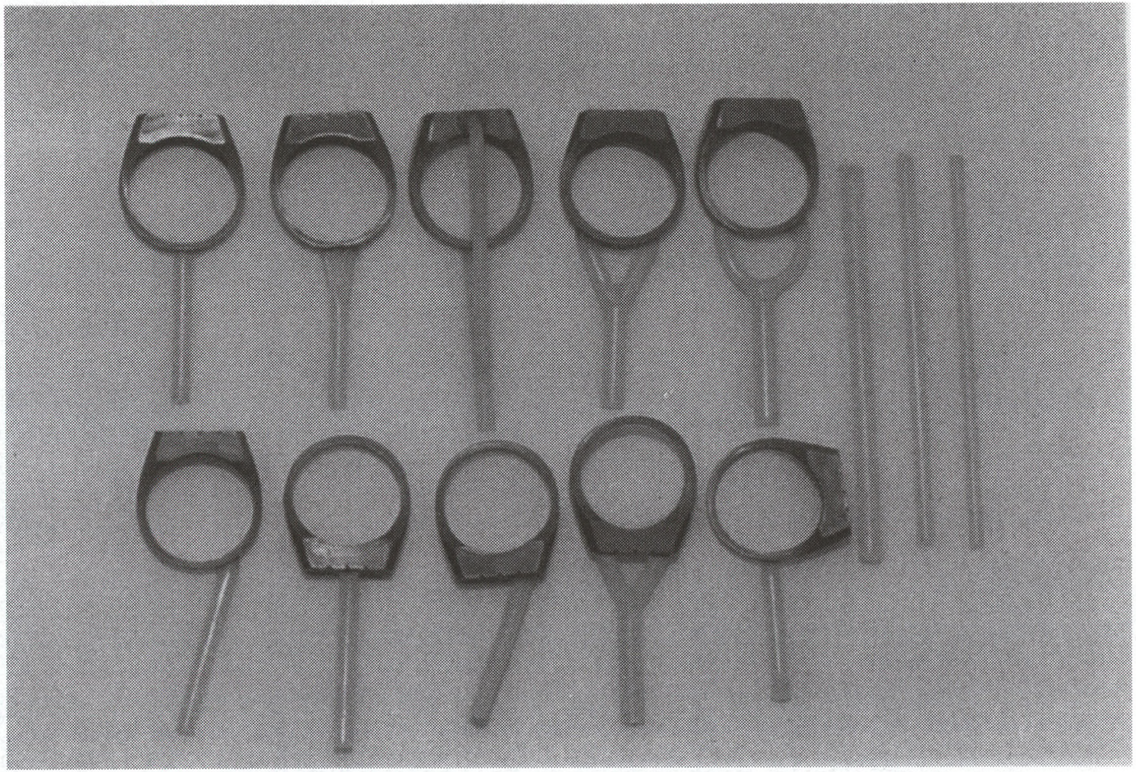


figure 3: A number of options for sprueing the items

How shall one sprue and tree properly?

<u>The requirements are</u>
1. Continuous filling
2. Turbulence free filling
3. Filling with a good metal flow

To do this, it is important that the caster has basic knowledge of metal flow characteristics. We will now examine different areas of the casting and which influence the flow of metal has on the quality of the jewelry cast.

THE METAL FLOW

a.) in the crucible

In vacuum/ pressure casting machines, where casting is done with pressure, the mer act of casting can be the source of problems already. If too high a pressure is chosen, the metal can spray. This means that from the crucible to the flask the metal will enter as a spray rather than one solid stream. During this spraying, there is the danger that gases enter the alloy mix, air bubbles come in, and oxidation form around the spray drops. Such internal oxidation will be visible as a „hard spot" during polishing.

A spray is created when a certain volume of metal is pressed through a small hole with high pressure. You can easily demonstrate this effect with a water faucet: The more you open the water, the wider the spray. In centrifugal casting machines, which use far more pressure, this effect does not occur. This is because the metal comes from the top of the crucible and not through a bottom hole. Therefore there will not be a narrow passage that can cause this effect.

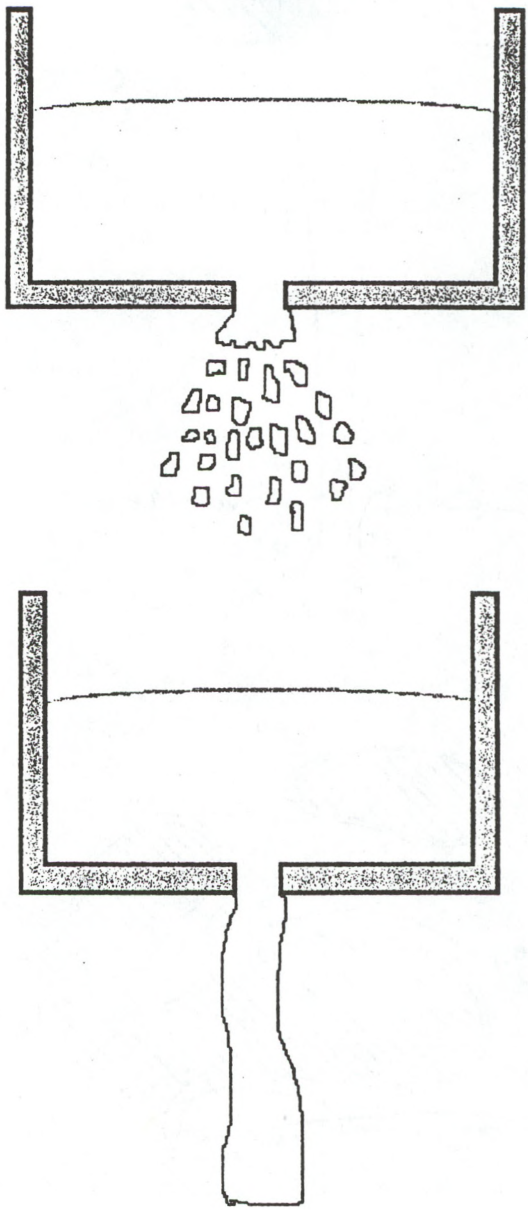


figure 4: above, high casting pressure
below, low casting pressure

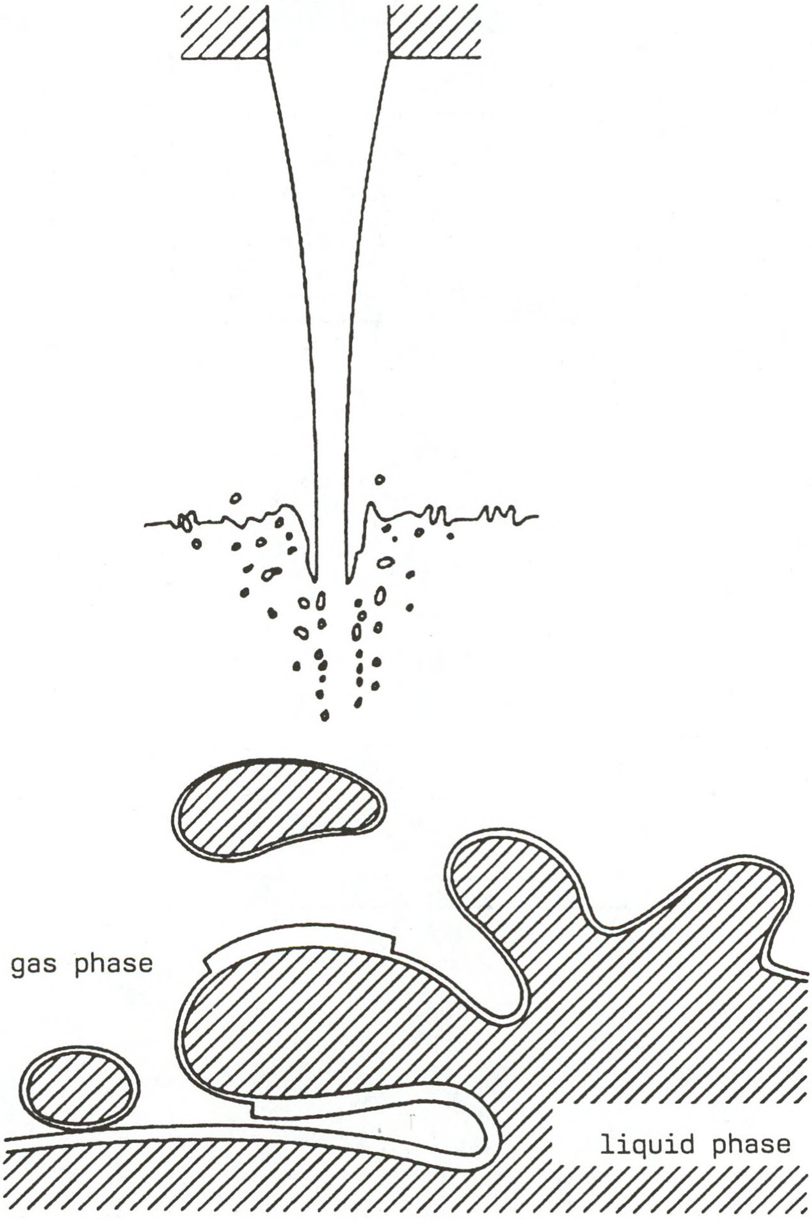


figure 5: above, showing mixing air and oxides in the melt below, building up oxid layers on the surface on liquid metal

b.) In the button and center tree stem

Here, at the beginning of the casting system, at the cone that forms the button, some considerations must be taken in to account. A smooth and slick funnel is important. Unevenness on the button will lead to unwanted turbulence as the metal enters. Another effect is the transition from the funnel to the stem is a separation of the metal to, what is called a "free stream" of metal. This stream will blend and mix with air and cannot be avoided in reality.

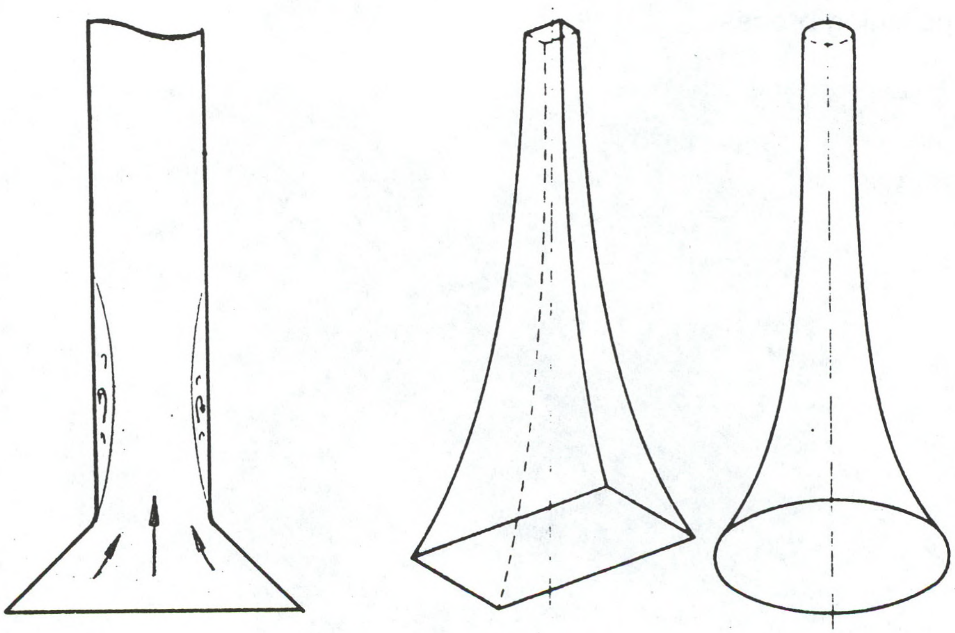


figure 6: left side, free stream
right side, two different types of casting stems

The thickness of the center sprueing stem is important. It should guarantee that a high casting speed is achieved, which is vital for good casting results.

Is the stem too thin, then the metal has to go through a tight squeeze which requires high pressure. This can only be achieved through centrifugal force. If because of to thin a stem, excessive casting speed is created, then the metal tends to spray, takes on air, gases and oxidation. An other problem too high a casting speed can achieve is the washing out of investment plaster. This can lead to fine inclusions of investment throughout the casting. One can see this defect as „hard spots“ in a casting during the polishing process.

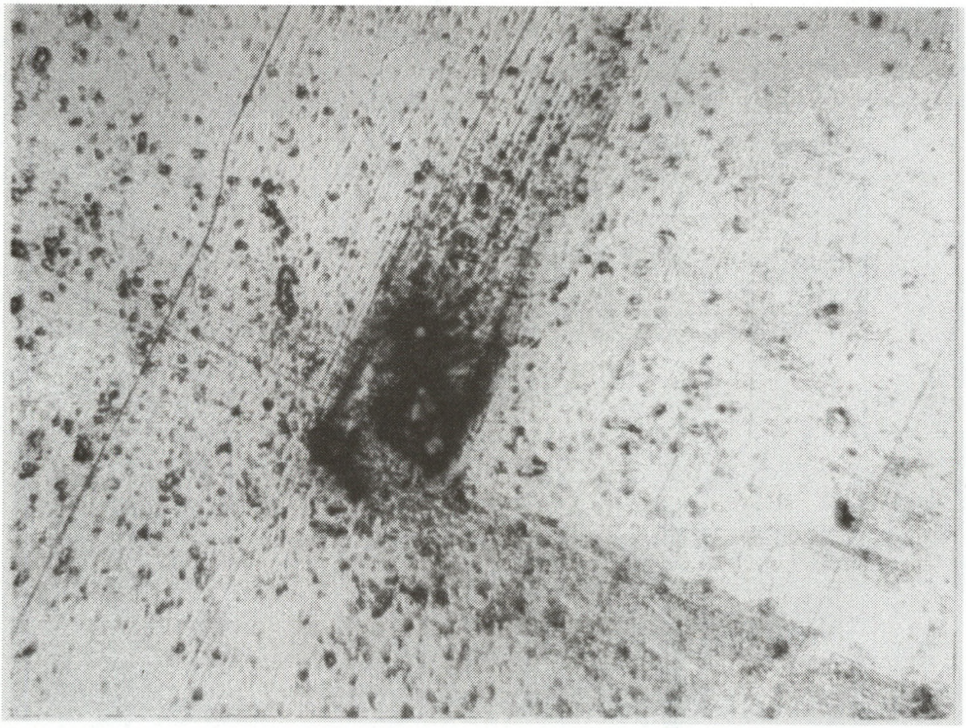


figure 7: polishing coma (hard spot) caused by oxides or investment inclusion

At this point I would like to mention the importance of a smooth interface from center stem to the sprue. If that is not done with care, and there are undercuts, the melt will create turbulence at this place too. Sharp corners of investment can brake off and become part of the melt, resulting in the before mentioned „hard spots".

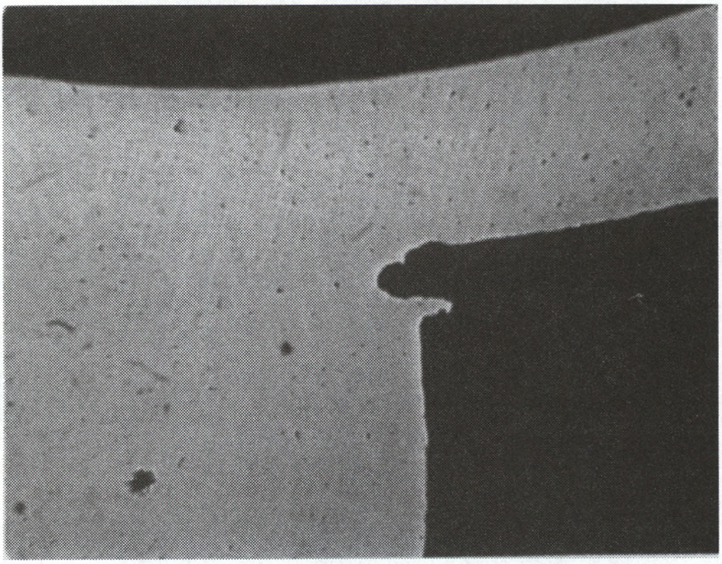


figure 8: cross section of a bad sprueing (undercut)

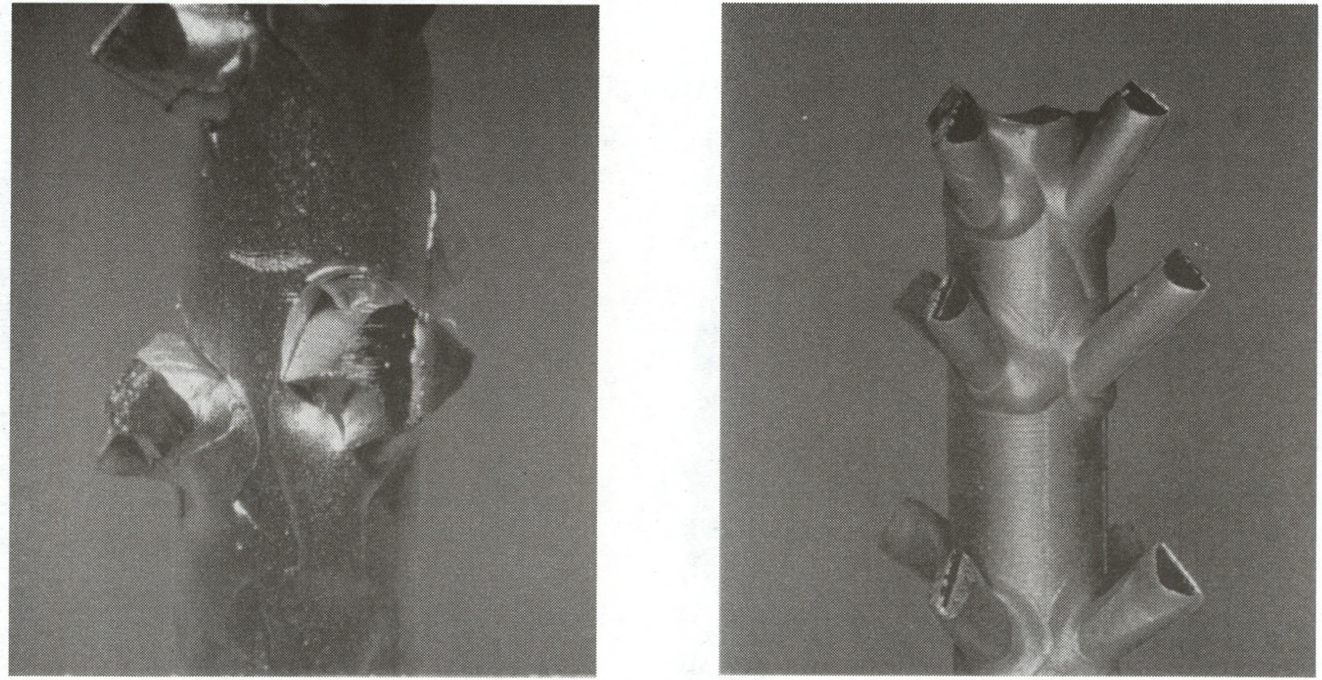


figure 9: left side, showing a bad connection between sprue and stem
right side, showing a good connection

Another problem with a center stem being too thin is the fact that it can freeze before the melt. As it has a connection through the cone to the cold outside air. If this is the case the melt will feed the stem and not the part cast.

The stem cannot be too big either, as that will result in a slow casting speed. Too slow a casting speed will lead to pores and non-fill or partial filling of the cavity. Especially if the distance the metal has to flow is large.

A good success has been achieved with a slight cone shaped stem. These systems fulfill the requirements of a steady decrease in diameter of the stem, which results in an increase in casting speed to the product without creating turbulence. Very good results were achieved with center stems that have a

cone angle of $\alpha / 2 = 1 - 1.5°$

diameter d1 = 18 - 20mm

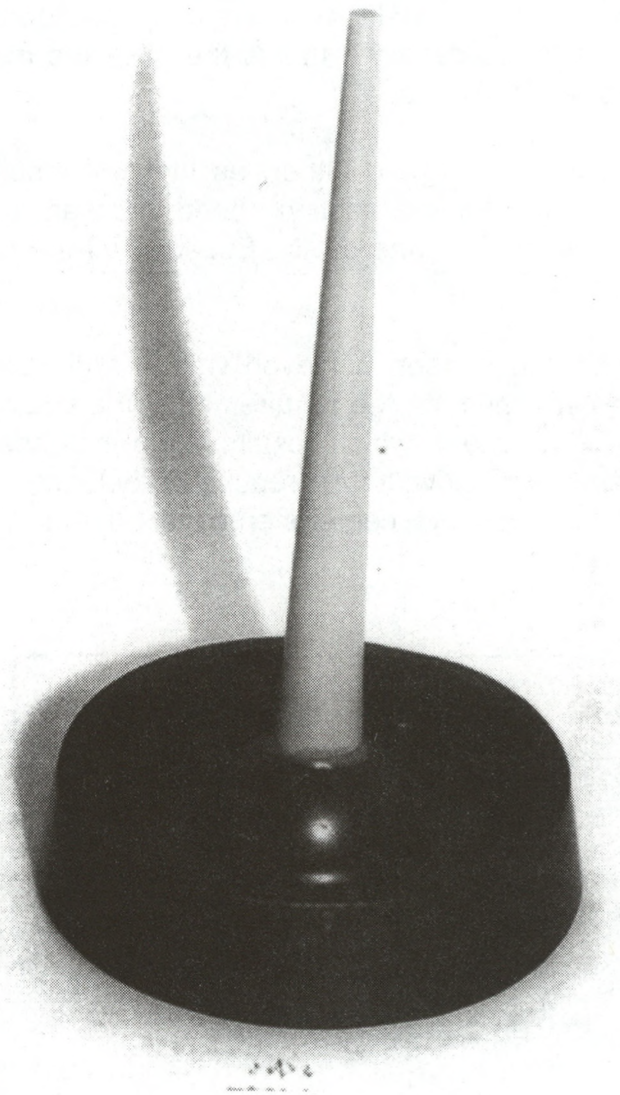


figure 10: cone shaped center stem

c.) in the casting system

The actual sprues have the same requirements as does the center stem. Here too, a slow decrease in diameter is desired. The sprues should be slightly cone shaped. The diameter should decrease particularly after a bend. This will prevent cavities on the inside of the bend, as well as air inclusion.

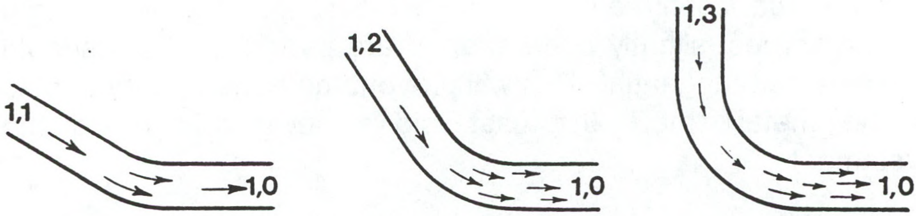


figure 11a: reduced diameter after a bend

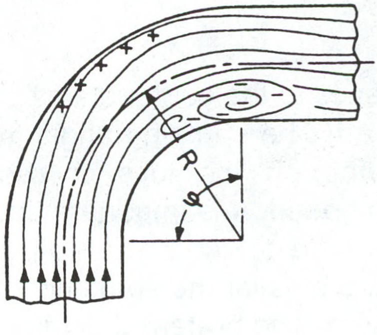


figure 11b: creating turbulence in the bend

The dimension of the sprue as it relates to the piece is of great importance. The cross section of the interface sprue/casting part should have the smallest diameter of the whole system. This results in the lack of extra metal in the cut-off area which could freeze last. The determining factor for the sprue size of this interface is the cross section of the actual piece to be cast. I will get back to this point.

The assorted spruing choices have been shown in Fig. 3. Which represents the best choice has to be determined through careful planning and confirmed through test castings. Simple straight forward sprues, slightly cone shaped are preferred. They should be connected tangential. This will prevent the forming of hot spots as the metal enters the cast, slows down and heats the investment.

At the interface sprue, to the casting turbulence is created. This is caused by a widening of the cross section. The turbulence can lead to the enclosure of air into the piece. This cannot be prevented. If sprues are use that branch out it is very important that they too have a reducing diameter, i.e. the two seperating sprues together should be thinner than the one sprue that they split off.

When waxing the pieces to the center stem some important things need to be considered. The sprueing angle from the center stem has a great influence on the loss of casting pressure and therefore the casting speed. It is important that the pieces sprued are as close as possible to the flask wall. A very small angle should be chosen. The smaller the sprueing angle, the greater the loss of casting pressure. The preferred angles are 40 - 45°.
As we are dealing with a seperation of the incoming metal at this spot, the wax should have a rounded interface from the tree to the sprue.

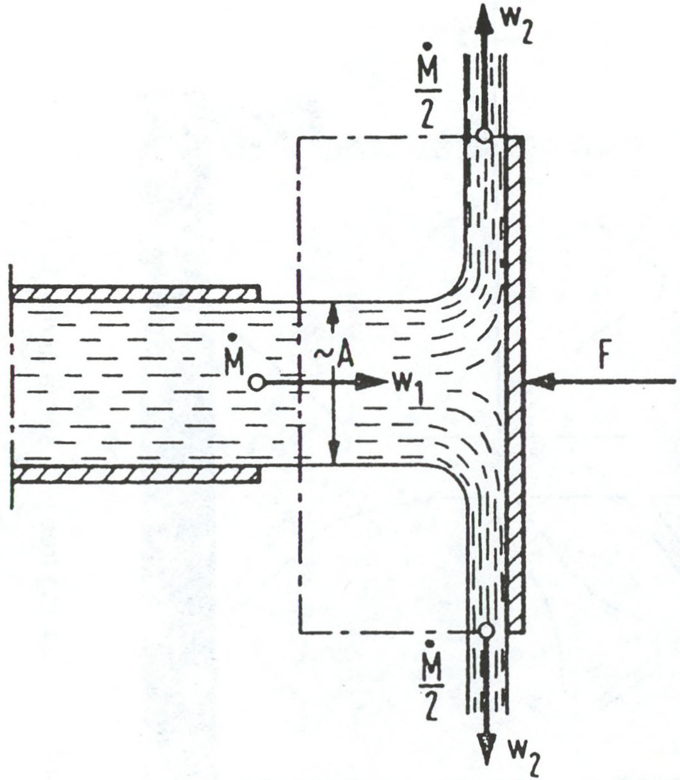


figure 12: drawing of a freeze plate

figure 13: cross section of a ring shank with porosity after building a „hot spot“

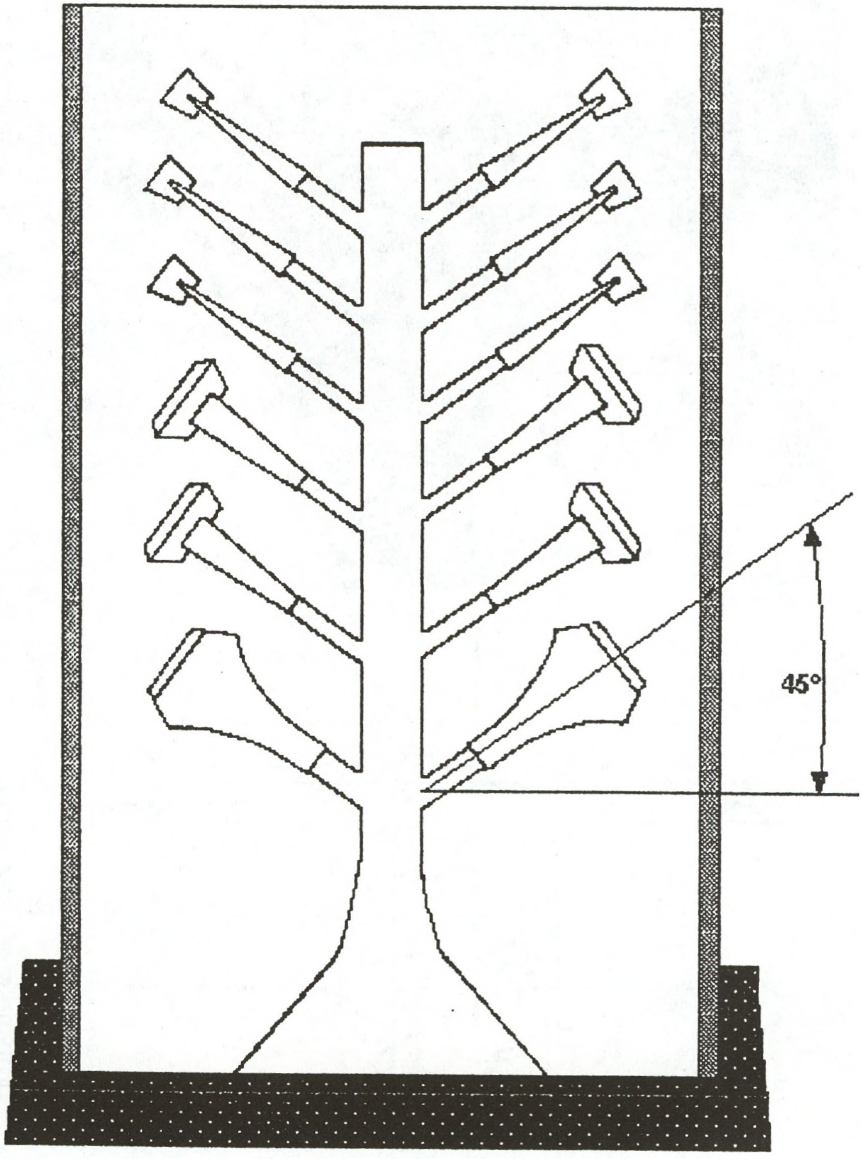


figure 14: casting tree with sprue angle

d.) in the actual cast part

A very important part of the success of a casting is in the cast part itself. Simple large geometric pieces are not typically made for casting and can be fabricated at a reasonable cost from sheet and wire. Most pieces of jewelry are created in the mind of designers. They create a final product which is not necessarily based on ease of manufacture. This makes sense as thoughts of technical nature might stifle creativity.

It would, however be desirable, if the designer and the caster discuss the design and solve minor problems at that time. Often a great design can be modified for ease of casting without major changes to the appearance of the piece.

Basic rules for castable designs

1. Avoid material clutter (figure 15)

2. Don't incorporate sharp corners, create radius in the design (figure 16)

3. Equal wall thickness (figure 17)

4. Avoid sudden changes in cross sections (figure 18)

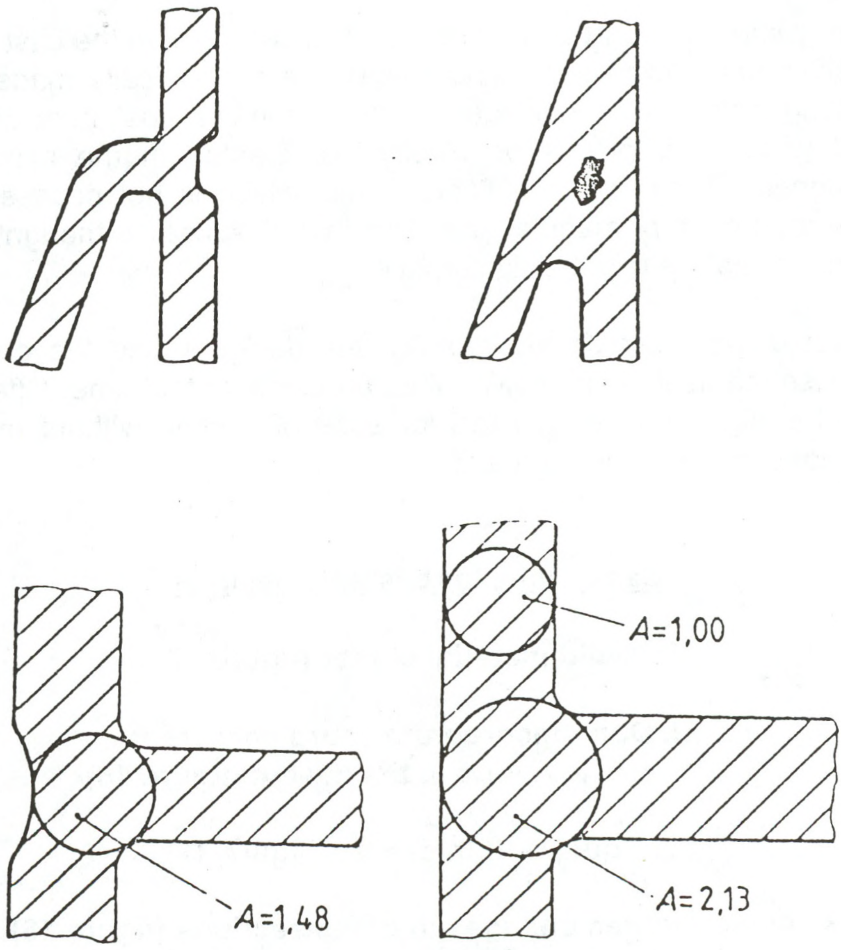


figure 15a: examples of point 1 (avoid material clutter)
left side right; right side wrong

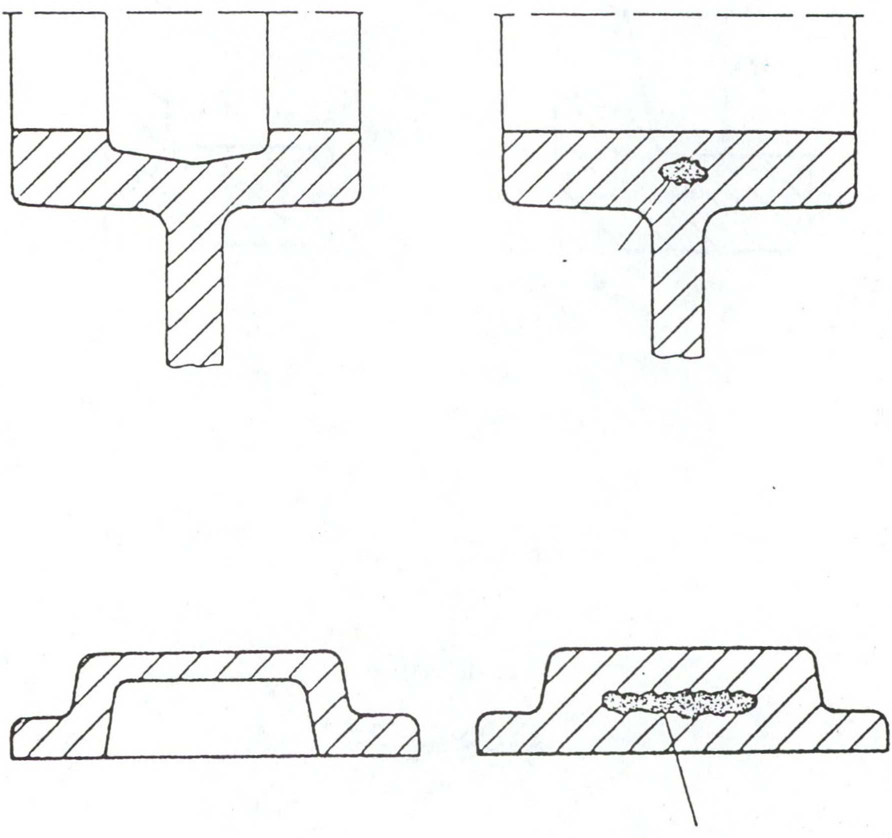
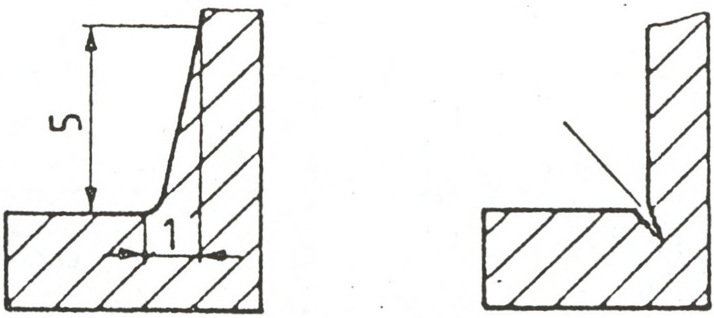


figure 15b: examples of point 1 (avoid material clutter)
left side right; right side wrong



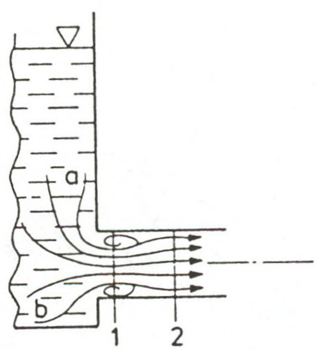


figure 16: examples of point 2 (don't incorporate sharp corners, create radius design
left side right; right side wrong

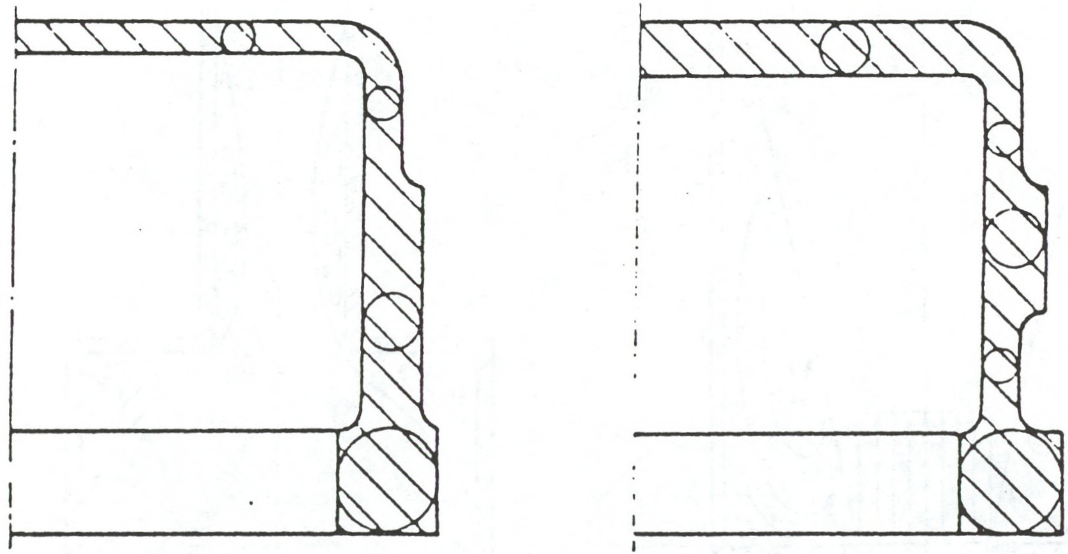


figure 17: examples of point 3 (equal wall thickness)
left side right; right side wrong

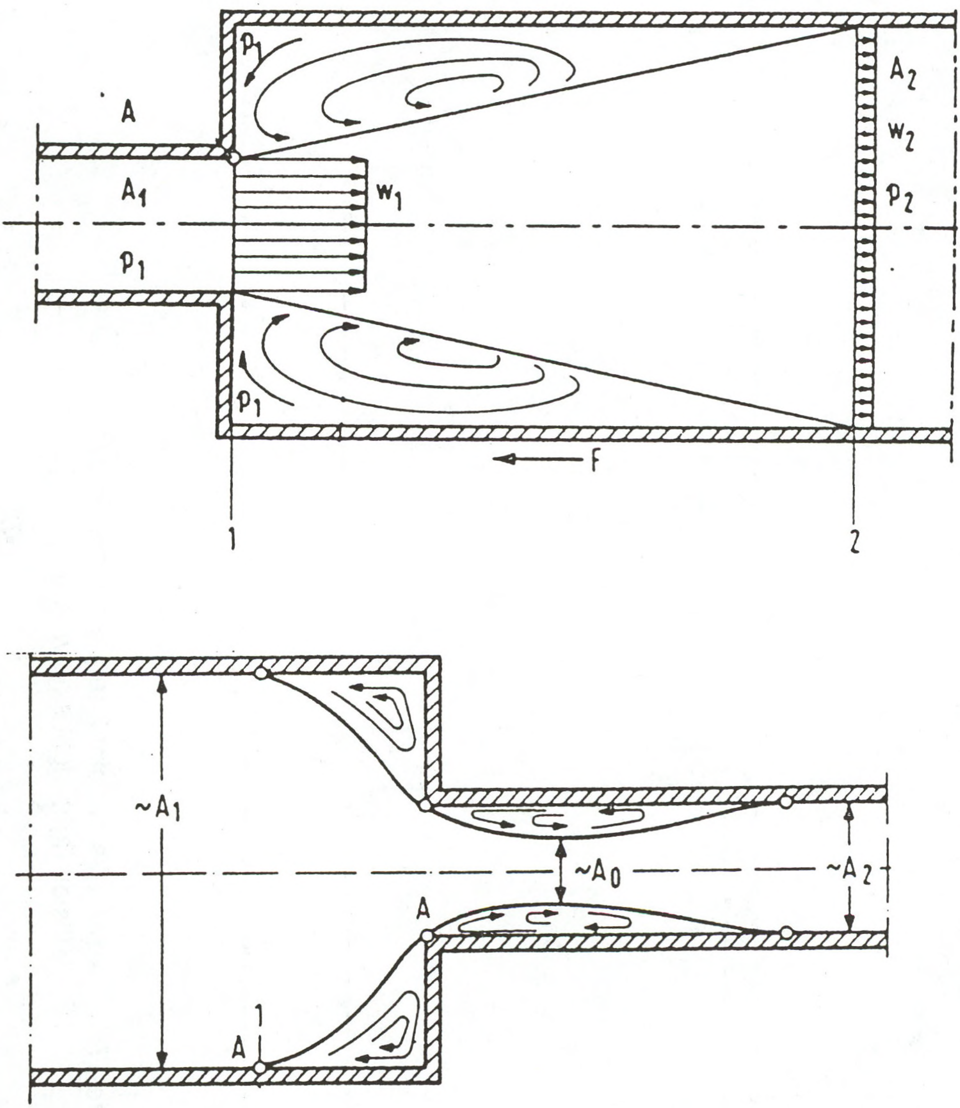


figure 18: examples of point 4 (avoid sudden changes in cross sections)
above diameter widening; below diameter reduction

If these rules are taken into consideration, the basics for a successful casting of good quality are established. If , however, even after careful considerations, the piece is still hard to cast, other options need to be considered. There is , for example, the option to cast the piece in several sections and assemble it later. That requires a cost study, to see if the additional labor and fabrication cost can be justified.

Once the design is approved and should be cast, it is important to determine how it should be treed Fig. 3 showed the many possibilities.

Another point of contention is the question as to the placement of the sprue on the model.
The choice the caster makes as to this placement may be in conflict with the view the jeweler has. The jeweler, who has to work on the piece, wants easy removal, and easy finishing without interference in the design. Lets take for example a ring with a massive top. Usually the sprue is attached at the bottom of the shank. This is where the ring is usually sized and therefore a convenient location for the sprue. The clean-up is also far easier on the bottom of the shank as it would be on the top. The caster however, knows that a sprue is not only here to fill, but also to feed the casting. This is why it is important to place the sprue at the largest mass of the design, which means in the case of the ring, the sprue should be on the top.

After the “where” the next question would be the “how” in Fig. 3 you see the typical cylindrical sprues. The best suited ones however would be the slightly cone shaped sprues you have seen on the center stem. These slightly cone shapes sprues fulfill the requirements of a small cross section decrease. This results in a increase of the flow speed and a decrease in turbulence of the melt, as it enters and fills the mould. The cross section of the casting canal must be smaller than the cross section of the piece at the interface.

Formula:

$$A_{\text{casting sprue}} = 0.5 - 0.7 \times A_{\text{cast item}}$$

To get good results the freezing should take place in the correct sequence. The freezing in the long direction should happen faster than the freezing in the cross direction. Important here is the flask temperature.

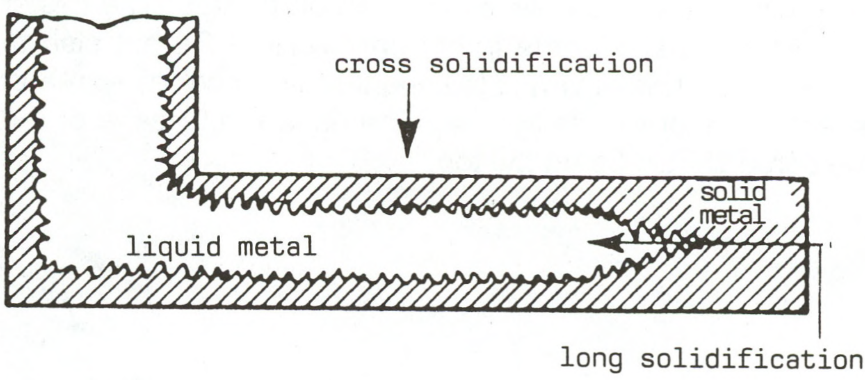


figure 19: proper freezing

We are examining the placement of the waxes on the tree. A tree, totally waxed up with the identical pieces makes little sense as the conditions for the casting vary with their position. The metal static pressure is markedly less on the bottom of the tree if compared with the pressure on the top. Therefore we have different streaming and feeding conditons. With increasing formfilling we have a reduction in the height between metal surface in the casting cone and in the cast. Additional we have a loss in the friction that means we have a loss in the casting pressure. For this reason the tree should be mixed , with the heavy and large pieces on the bottom, followed by medium sized and then by small filigree on the top. The filigree pieces should be on the top as that area fill first and fastest. Sprueing nearby the casting cone makes no sense depending on the loss of casting pressure.

It is important to decide as to how many pieces should be placed on one tree. Often the capacity of the casting machine is used as criteria. This is only partially the case. To tight a placement of the waxes on a tree has its disadvantages. To achieve a proper directional freezing of the metal, certain thermal conditions need to be considered. One of the requirements is regulated heat dispersion. If the cast pieces are too close together, the heat of one will add to the next and can lead to a localized over heating. Which can result in a metal-mould reaction and surface damage. Furthermore, the gases which flow ahead of the metal and are absorbed through the pores of the investment, will end up in the next cavity and can create porosity through air enclosures.

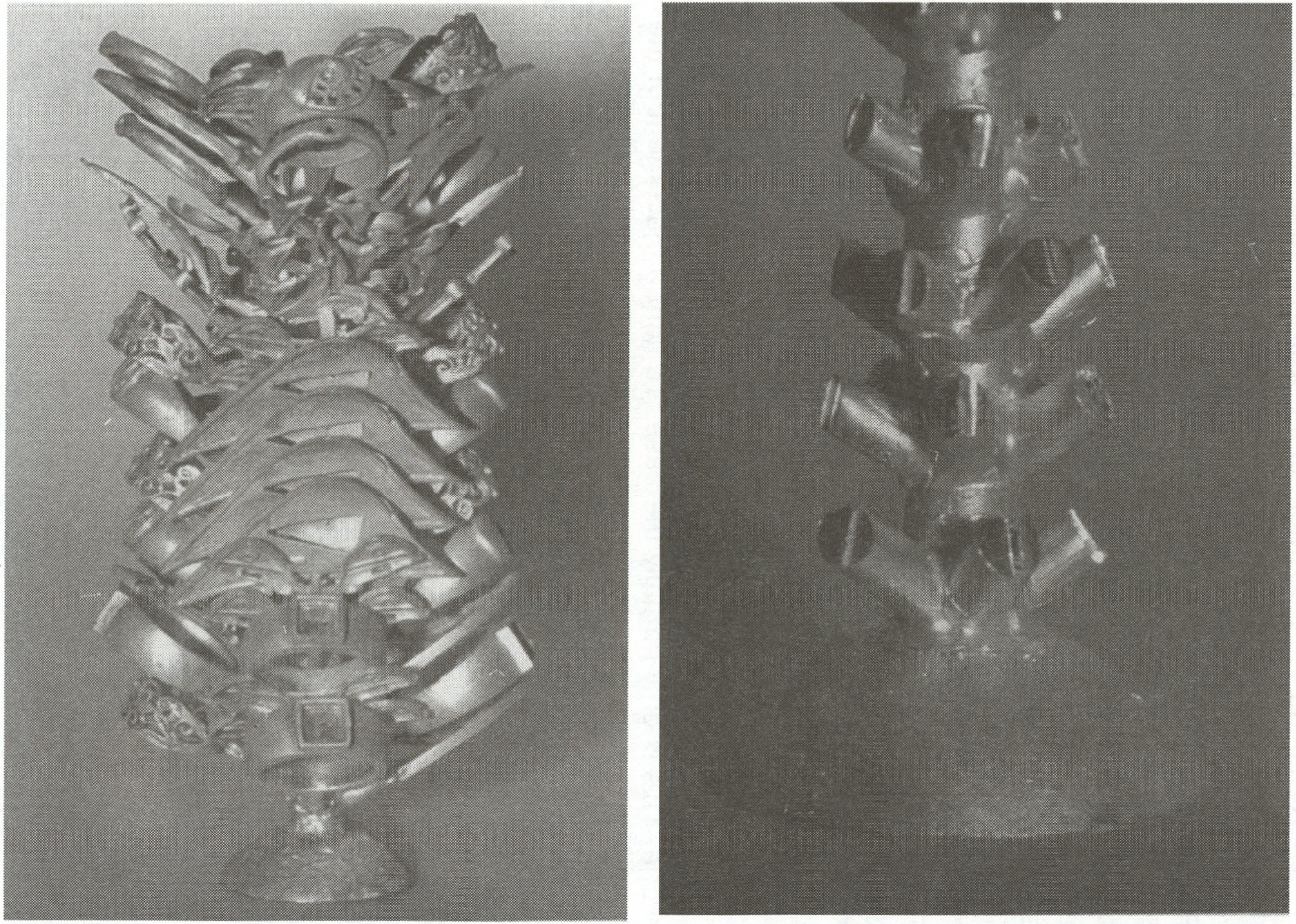


figure 22: left side, tightly sprued tree
right side, spruing at the button cone

OBSERVATIONS OF PARAMETER CHANGES AND SYSTEMATIC CASTING CONTROL

If changes are being made in a casting process, the effects are sometimes judged in a subjective manner. This can lead to a wrong interpretation of the effect. Old habits and mistakes are being justified and manifested. To identify a change to the positive, one must totally understand the process. This is not possible in a subjective manner. Systematic steps of evaluation the casting results are required. Minor changes are often not seen as being significant. As many effects overlap, it is not usually possible to recognize them by examining just a few castings. A long term observation and recording is needed to get statistical information. Only then it is possible to see if the actions for correction are heading in the right direction.

A good tool is the failure collecting card. It should be kept up to date and include each casting separately. If done properly, it will provide statistical information about spruing, placement on the tree, alloy cast and casting temperatures as well as flask temperatures. The most important entry on this card is the good/bad determination. If there are casting defects on the piece, they should be described in detail as to placement, type and severity.

So it is of great importance that this information follows the finishing process of the piece, and is reported to quality control. The individual departments need to work together and communicate the casting problems, so that they can be solved at the source. This is a never ending process.

Failure collection card	
customer: model no.:	

date	material	number of casting parts	type of defect												number of good parts	number of reject parts	% rejects
			surface defect							volume defect							
			cracks	shut	chared investment	shrinkage cavity	porosity	microshrinkage	incomplete filling	shrinkage cavity	porosity	microshrinkage	oxide inclusions	investment inclusions			

figure 21: failure collection card

Summary

Process control for the optimizing of the casting process is mandatory in today's industry. Just as important is the understanding of the diverse parameters and the influence they have on the casting

Of very great importance for good casting results is the control of the metal flow. A turbulence free rapid filling of the mould is the goal. To reach this goal, one must understand the conditions of the stream of metal as it comes from the crucible to the cavity to create the casting piece. This requires the basic understanding of the flow.

Many of the parameters discussed are most likely already common knowledge in the industry, and are most likely being successfully applied. It is important to me to inspire thought about the connection and interaction of these things and question everyday "know how" with a critical eye. Once it has become a habit to analyse the influence parameters and the results, there will be many opportunities to improve the casting process through informed action.

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