Marine Hardware: Experiencing the Foundry men’s Craft

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Design to the finished product

ABSTRACT

This paper is written to inspire and educate those interested in the finer skills and processes required to produce high quality castings. It is a treatise of the process from design to the finished hardware learned during more than thirty years of practice. From factors to consider in casting design, the types of casting processes, characteristics of the common alloys, fundamentals of patternmaking, a summary of operations on the foundry floor, and finishing the casting process through final machining and inspection you will find it all discussed here.

INTRODUCTION

This paper is generated from the hands-on knowledge and experiences as it applies to our foundry operation and the projects that we have completed. Thirty plus years I have spent working in the metal manufacturing industry and there are still things to learn and challenges to overcome with almost every project. That may be the one main reason that I have fallen so deeply into the processes. By taking a concept, a broken or worn out part, applying the science, then the skills from many different disciplines and putting them together in a very carefully guided way we can create some of the most simple, functional and beautiful hardware. The start is easy "form follows function" and the aesthetics will naturally follow. Remember to use the K.I.S.S. principle (*keep it simple stupid*) as a check and balance when it comes to designing and planning the process to be used to make the parts and pieces you are after. This will make the involvement with the foundry and the overall project, that much more rewarding and timely.

DESIGN

This can be one of the most interesting aspects just due to human nature. Everyone sees things differently; from the sketch on a paper napkin to the DWG 1234-56 provided by the US Navy, the designer and pattern maker may interpret it very differently. Then go about producing the pattern in his or her own way, even though the end result is still the same part. The casting design should be coupled with the foundry practice, process and alloy to be used from the start. This will cut down the time involved and the overall cost. The processes that we use to make the paper napkin design part and the DWG 1234-56 drawing are the same even though we may have to meet standards, such as SAE Aerospace, AMS 2175 (Aerospace Material Specification) as well as ASTM (American Society for Testing and Materials) ranging in Class 1-4 and Grades A-D. We must stress that the temptation to over engineer parts will only make the process long and drawn out, tooling expensive and then the final product will cost more. The best designs fit into the class and grade of part that is required for its function. These are benefits to customers, designers and/or end users knowing that the foundry can produce castings of this nature.

Design for the number of parts you will need. If it's only one, then loose molding patterns is just fine for us. Other foundries may require a higher degree of tooling if staff is not knowledgeable in all the loose molding techniques. If twenty or more parts will be needed at any one time, plan for match-plated patterns.

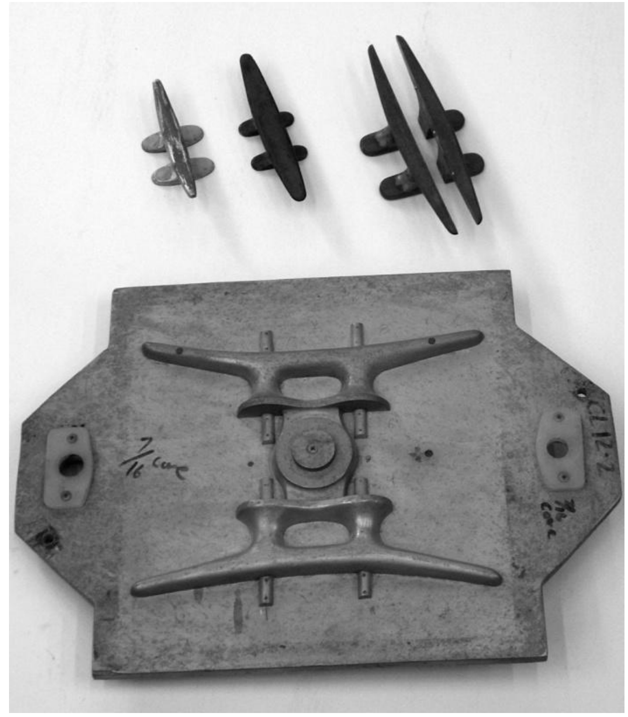

Figure 1- Top left to right. Repaired broken part, center is a wood carving, right is a split pattern and bottom is an all-aluminum match plate.

Figure 1 displays the different types of patterns we have used. The top two are solid models; it may be a carving or a repaired broken part. These types of patterns require the most knowledge and skill of the foundry man/molder to produce. They may be less costly for the customer to provide, but will require more labor throughout the casting and finishing process, in turn costing more in the long run. This will also reflect the most shrinkage in size on the final piece. Making parts from "parts" is not the best practice.

Third in line is a split pattern for loose molding. The parting line is all on the same plane and easily molded. Dowel pins are in place in the cope side of the pattern for alignment. This only requires good gating and feed system practice by the molder. These are best for short run or one off castings.

Fourth and below is the match plated pattern geared for higher production and has the least amount of labor for the higher return of parts. Patterns are fixed to the match plate on both sides, all the alignment is made prior to molding, along with gating, risers and flask guides.

We will revisit some of these details in more depth as we proceed into pattern making, alloys, etc.

PROCESSES

We use a number of casting processes to produce the wide range of cast products. Greensand molding, chemically bonded sand molding, investment or ceramic shell (lost wax) and digitally printed molds and cores.

Our greensand process is natural olivine sand mined in several parts of the country, for us, right in Washington State. The sand is purchased in varying grain size depending on the castings to be produced. In general we use a #90 to #120 grain size to achieve a very smooth surface finish. The sand is prepared by "mulling". This process coats the grains of sand with a layer of clay and water to bind the sand together for molding. The clay is both western and southern bentonite. During the mulling process the clay, water and sand are rolled together to build what is called its "green strength" that will allow the molder to ram the sand around the pattern and then remove the pattern without losing the shape or detail. For good castings the amount of clay and water must be maintained at the proper levels or failures will continually plague the operation. This sand is unique in that it can withstand the thermal shock of metal poured into it at temperatures that can exceed 2300 degrees. Olivine sand maintains its grain size and this helps the overall permeability of the mold. (Permeability is the ability to let gases pass through the internal walls of the mold.) By not fracturing the grains of the sand, it remains coated with clay. Therefore it can be used over and over again. Proper preparation is required before the next round of molding can take place.

Chemically Bonded Sands

There are many types and suppliers of these products. We will go over the ones we use in house to produce both molds and or cores. Cores are a third party to the mold itself and will be discussed in further detail later.

The main type we us is a No-Bake Binder system called "Pep-Set" supplied by Ashland Specialty Chemical Co. It is a three-part phenolic resin, polyisocyanate resin and series of catalyst activators. This system can be adjusted to very fast or slow cure rates and castings can be poured in minutes of being stripped from the core box or mold. The system usually uses sand with a low or neutral ph, although we use a 60/40 blend of silica and olivine to achieve a very fine surface finish. It does not require exposure to oxygen or to be gassed like CO_2 set sodium silicate binders. With the ability to adjust the cure rate we have made cores that weigh only ounces to molds weighing 2700 pounds. As with most resins, there are other requirements when working in this material. You will need to use the recommended release agent for the removal of the patterns or cores from the core boxes. In Figure 2 is a sample of a small core, the part it is used to make and the core box and Figure 3 is a large cleat mold made in this material.

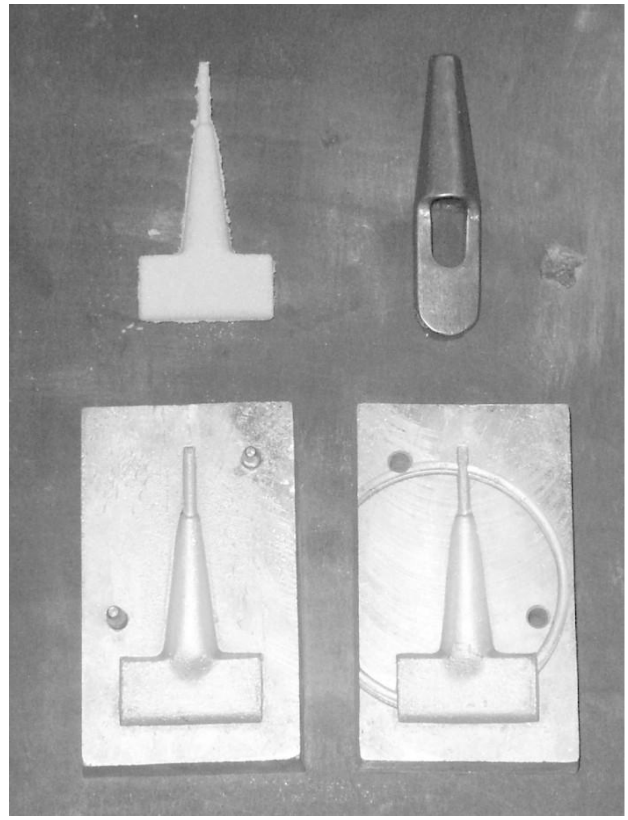

Figure 2- Top left is a core made of Pep-Set. Its weight is less than an ounce (note the tip of the core is only 1/8" dia.. Top right is the un-machined casting and below is the two-part aluminum core box.

Figure 3- This half of the large cleat mold is 8 ft long, 3 ft high, 1 ft thick and weighs over 800 pounds.

Investment or Ceramic Shell (lost wax)

This process can achieve high levels of 360 degrees of detail down to fingerprints left in the wax. Most marine hardware would be more costly using this process. Very high production or detail in the form of art or machined tolerances will offset these expenses.

The process starts with wax models being produced either by hand, from rubber molds and/or aluminum injection molds. All of the tooling associated with this first step will have a varying degree of cost.

Once the wax model is produced it can be cast as an individual part, with the addition of the sprue, runner and risers; or assembled on a tree or a cluster of parts that will provide for the proper filling and feeding aspects needed to deal with the shrinkage as the part cools.

The older style of investment is done by pouring plaster over the wax form or by suspending a tree or cluster in a container, either way; you end up with a block, cylinder or shaped mold with the wax inside. Once the plaster is dried, the whole mold is placed in a kiln and the wax is burned out leaving internal voids where the metal will flow. Care needs to be taken at this point, that the moisture content of the mold is very low and the heat applied in the kiln is slow and gradually increased. Once the wax and all carbon residual are gone the mold can then be poured. All of these steps require patience and strict following of proper procedures or all can be lost at any stage of the process. If you plan to use this process just remember the name "Lost Wax" as a guide to keep you on track. If you have not created "master molds" your wax will be lost.

The new investment "Ceramic Shell" is also lost wax; it has some advantages and also some strict details to adhere too. It consists of colloidal silica (liquid) and fused silica flours mixed and held in suspension, known as the slurry. The waxes, trees or clusters are dipped into the slurry and then coated with dry, coarser fused silica sand. At this point the parts start to take on an appearance of odd sugar cookies. See Figure 4. The process is repeated over and over until the proper amount of shell is built up. Depending on the size, weight and number of parts being done there can be 6 to 15 layers. All of this takes place in a climate-controlled room for both the slurry and for drying of the shells. If the temperature and humidity change too much the wax will expand or contract leaving theshells with fissures on the surface or even worse the shells cracked. The slurry must be maintained for proper ph and mixed continually (24/7) to keep the solids in suspension. It also requires frequent checks and/or adjustments to keep viscosity in the proper range. Now that we have overcome those hurdles, we can move to the removal of the wax from the shell. This can be done either by a flash fire kiln or autoclave with steam. For us the flash fire kiln works out best to de-wax the shells. A hand torch can first remove the majority of wax from the sprue or riser, and then placed in the kiln the burn out process is continued until all the remaining carbon is gone. They can be poured right away, with the temperatures of the shells up to 1700 degrees or allowed to cool, poured at a later date and or reheated to proper temperature for pouring. See Figures 5 & 6.

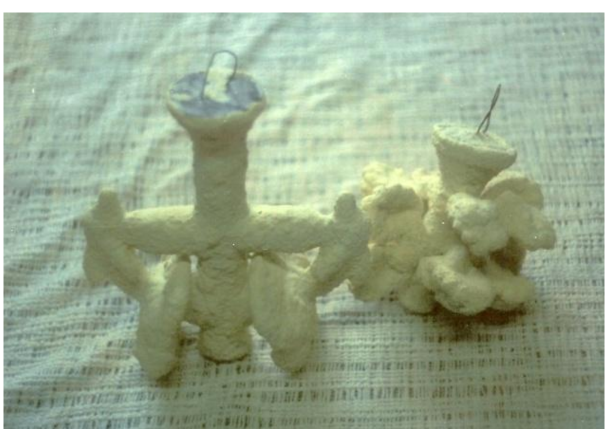

Figure 4- Ceramic shells with four coats and back up dry sand.

Figure 5- Shells being poured in a dry sand bed for support. This is after wax has been removed.

Figure 6- Shell removed from castings.

Printed Mold Technology

This method has some real benefits that can be realized all the way from the design to the casting. We start with a CAD or solid model program, and design the part or reverse engineer from an old one. We then add the needed feed and gating system to the part and draw the mold around this package. Convert it to a STL file so the printer can do its part. How this all comes about is the STL file is used to instruct the printer how many layers and where to catalyze the sand.

The current machine that we have access to is owned by the U.S. Navy and operated by the Ex- One Company. It has a print head of approx. 58" x 36" and can build up to 30" total height of the print. It starts by treating the sand as it is entered into the print head and spread in a three to five thousandth of an inch layer and the printer head comes along and places the catalyst in all the right places to start the building process. This is repeated until the mold and or a core is produced. The height can be more than 200 layers per inch and the printer can run nonstop for up to forty eight hours for a full print box filled to capacity. When competed the fill box is removed from the printer and excess un-bonded sand is carefully removed from the molds and/or cores. Figure 7 shows a difficult and very complex vacuum rotor done by this process. Figure 8 is the drag (bottom of the mold), Figure 9 is the cheek (center) and core portion, Figure 10 is the cheek assembled on drag and Figure 11 is the whole series of mold parts with cope (top of mold) in place to form the assembled mold package. The more complex the part the better it works in terms of time and tooling. No patterns or core boxes to make, so a pump impeller becomes quite easy to produce, all of the cores, cope and drag portions can be printed at the same time or as intricate parts within each other.

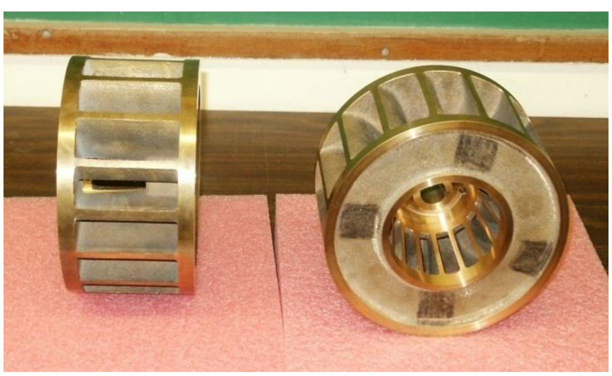

Figure 7- Vacuum rotors cast in alloy C90300 Navy "G" tin bronze

Figure 8- Printed mold drag. Note the runner in the outer ring, with a basin where the sprue will attach. This allows metal to enter the casting in four points (gate)s all at the same time.

Figure 9 – The face is the bottom of the cheek and core section. Note the square hole at the top; this is the sprue and also where it connects with the runner. To the left and right below the sprue are the four in-gates and risers Very top left and very bottom holes are for alignment on the drag.

Figure 10- The cheek and core section placed on drag, showing rotor veins, continuation of the square sprue and round alignment pins to locate the cope.

Figure 11- The cope (top of mold.) To the left is the pouring cup or basin, the top of the sprue (square hole), five larger holes are risers and the four small holes are vents from internal risers at the gates,

THE MATERIALS WE USE- AND WHY

We will start with the alloys and their UNS numbers (unified numbering system) of the most common alloys we use listed in our order of preference.
C87300 Everdur silicon bronze- One of my favorite alloy's.

C95500 Aluminum bronze- Also a top choice of for both its high strength and corrosion resistance.

C86500 Manganese bronze- Has its place and needs to be applied properly for its best use.

C99750 Bronwite- Also referred to as white bronze, German silver or Tombasil. The unique thing about this alloy- once it is polished it has the appearance of chrome plate or stainless steel.

C90300 Navy "G" tin bronze-

C92200 Navy "M" tin bronze-

C83600 Red brass- Sometimes referred to as Gun metal.

Before going into the details of these alloys displayed in the Table we must stress that in working with hot liquid metals, your personal safety is of the utmost importance and proper protective gear must always be used.

Values on alloys are rounded to the nearest percent and elements below 1% are omitted for ease of remembering each alloys base components. The strengths, yield and elongation values are based on the individual lot or heats in which the alloy was made.

In finishing this section I must remind you that the first four alloys are our top choices, but are not the only alloys in these categories. Just like ice cream there are many flavors to choose from. In the silicon bronzes alone there are 7 main alloys, 8 different aluminum bronzes, 5 different manganese bronzes, 3 different white bronzes, 19 different tin or leaded tin bronzes and 7 leaded red brasses.

We use the ones we do because, first corrosion resistance, strength, expected yield, working performance in the field, how they perform during the casting process and finally the working environment in the foundry. We only use certified alloys in our castings; why because scrap is only good for making one thing, bad parts! Just try to imagine taking all the above-mentioned alloys and combining them. Figure 12 shows ingots of certified alloys.

Alloy	Elements	Properties (Tensile, Yield, Elongation)	Pour Temp. (ºF)	Comments
C87300 Everdur silicon bronze	94% copper, 1% manganese, 4% silicon	TS- 45000 psi; YS- 18000 psi; Elong- 20%	1850-2150	User friendly in the casting process and can be repeatedly melted without changing its composition. It is very important for marine gear that this composition is maintained for proper corrosion resistance characteristics. A very narrow solidification range can be controlled by the founder and is more forgiving for the novice in terms of casting defects. Friendly to the foundry environment because at high temperatures it is not burning off zinc or other trace elements that can cause severe respiratory hazards. Easily welded and formed after casting, as long as proper procedures are used.
C95500 Aluminum bronze	82% copper, 4% iron, 4% nickel, 10% aluminum, trace elements usually less than 0.50%.	TS- 96000 psi; YS- 48000 psi; Elong- 7%.	2000-2350	Requires more care and attention to good foundry practices in both molding and pouring. Can be repeatedly melted with minor additions of new ingot to maintain proper composition. A narrow solidification range, but can be more difficult to control; it can start to solidify in many places at once in the casting. To help overcome this, larger and sometimes insulated risers are used. Has a tendency to form dross during the pouring process and it must be controlled within the feed system. Can produce some fuming during the pouring process. Can be hot forged after casting and welded, but is not well suited to cold working. All these after-casting processes require a fair amount of expertise with this alloy.
C86500 Manganese bronze	58% copper, 38% zinc, 2% iron, remainder is trace elements	TS- 70000 psi; YS-of 29500 psi; Elong- 20%.	1750-2000	Care should be taken as the zinc can be burnt off, so approx. 40% addition of new alloy ingot should be used with all re-melts to maintain proper composition. Easily over heated and the zinc will continually burn or flare up during the pouring process. Due to burning zinc it can create large amounts of dross that will need to be controlled in the feed system. A wide solidification range and will require good foundry practice in both molding and pouring. Can be controlled for directional solidification with the use of chills and will require risers at all un-uniform cross sections or shrink voids will form. Easily hot forged after casting; it is best brazed if welding is needed. Uses include propellers, stanchions, deck gear or other above water parts that may require bending prior to installation and/or be subject to high loads or bending type damage in use. Propellers that can be re-pitched by hot forging are a common use of this alloy.
C99750 Bronwite	60% copper, 19% zinc, 18% manganese	TS- 60000 psi; YS- 30000 psi; Elong- 35%	1650-1850	A very narrow solidification range allowing a little more forgiveness in the molding practice. Due to the high level of zinc care should be taken during the melting to not over heat and additions of new alloy ingot are recommended with all re-melts. Can be worked after casting with care, can be soldered or brazed and is easily machined.

Alloy	Elements	Properties (Tensile, Yield, Elongation)	Pour Temp. (ºF)	Comments
C90300 Navy "G" tin bronze	88% copper, 8% tin, 4% zinc	TS- 40000 psi; YS- 18000 psi; Elong- 20%	1900-2100	A very narrow solidification range allowing for thin to thick cross sections to be cast without defects. The pouring characteristics of the alloy are different than those previously mentioned. It produces a large volume of slag during the melt process and tends to pour through a skin like that of aluminum alloys. Rework after casting is not recommended. The vacuum rotors of Figure 7 are a common use because of the good wear properties of the alloy and the fact that the rotor can be spinning at high speeds in various wet and dry environments. Also notice the varying cross sectional thickness changes.
C92200 Navy "M" tin bronze	88% copper, 6% tin, 2% lead, 4% zinc	TS- 34000 psi; YS- 16000 psi; Elong- 24%.	1900-2300	For the most part has the working characteristic of the Navy "G" alloy both in solidification and pouring. Rework is not recommended. Used mainly for its wear properties in products like bearings or pump impellers and rotors where spinning parts may come in contact with machined surfaces.
C83600 Red brass	85% copper, 5% tin, 5% lead, 5% zinc	TS- 30000 psi; YS- 14000 psi; Elong- 20%.	1950-2350	A narrow solidification range. Creates a large amount of slag and is susceptible to gas absorption during the melt process. This can be overcome with a good melting practice and the use of degassing additives. Tends to pour differently than all the rest and can have cold shuts in castings and or gas related defects if pouring is inconsistent or interrupted. Not as environmentally friendly in the foundry due to the amount of lead, zinc and the combined effect they have when burning off at the higher temperatures. Addition of new alloy ingot is required to maintain composition. Used in mostly high production products as a substitute for better alloys because of lower cost of material and labor to work it. Soft, easy to grind, machine and polish.

Figure 12- Left is Everdur silicon bronze, center is aluminum bronze and right is manganese bronze. These ingots weigh on average 18 to 24 pounds.

PATTERNS AND PATTERN MAKING

These are some of the basic fundamentals that will help the novice and beginning pattern maker achieve a successful casting. The pattern maker should always ask for input from designer and foundry to ensure everyone is on board with the intended end use, the number of parts to be made, the alloy, the molding process, machining requirements and final finish of the part. This information will prove invaluable as the project moves forward, especially on complex castings. For most general pattern work in wood we keep to tolerances of 1/64th of an inch or less.

Types of patterns vary greatly, first are models and they are just a representation of the part needed. Second is a loose molding pattern, split or drafted all the same way from a parting plain. They may also incorporate follower boards, core prints and core boxes to achieve the desired part. Third are the match plates for short, medium and high run numbers of parts.

The models in Figure 13 are an easy way out for the end user to show what is needed, but making parts from them will require the foundry to spend more time in the molding, finishing processes and will cost more as a one-off in the long run. We try to avoid this, as it is not the best way to start into the casting process.

Figure 13- Top left is the worst that one might see, a stanchion base made with dowel, plywood, bent steel rods and assembled with 5200 adhesive. Bottom left a simple carving of a small D type shackle; top center a small Genoa track car with core print, but no established parting line and the needed split core box is on the right. The red car pattern in the center is at least drafted to release in one direction, but with no core print or box for the T- track slot this part will require more time in the machining process.

Loose molding patterns that are well done, have a predetermined part line as shown in Figure 14, the Genoa car is a simple split pattern with half face core box , the other is a large sail slide pattern with split core box. The black surface of the pattern is called a core print and this will support the core when inset into the mold. Figure 15 is patterns showing a multiple parting plane with follower boards. Note that the follower boards allow the parting line to change while also holding the pattern in place for the start of the molding process.

Figure 14– Left a Genoa car for 1.250 T-track, split with dowel pins, black core print, with half core box above. Note: the core box surface is coated with a release agent. Right is a large sail slide split pattern for 1.250 sail track with split core box above.

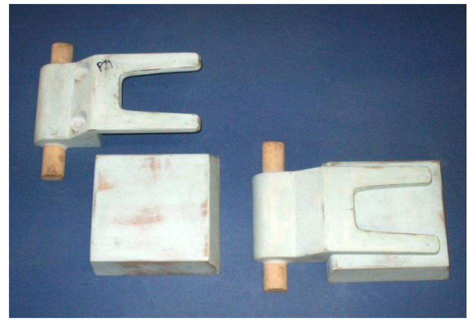

Figure 15– Rudder gudgeon patterns with follower boards and stock round core prints. Upper left is the follower board moved to show the change in parting plane. Note the draft and radius edges on both pattern and follower boards.

Match plates can be as simple as a single pattern or multiple patterns mounted on only one side of the match plate, as seen in Figure 16. They can vary from an easy two-pattern lay out to those having many parts on them. The match plates are made with feeding and gating system as an integral part of the layout. This relieves the molder from handwork in the mold and ensures repeatable success. The feed system consists of the sprue location, runner, in-gates, risers, and vents, all designed for the alloy from which the parts are to be made. See Figure 17.

Figure 16– Star match plate with runner attached on the drag side of the plate; in-gates and sprue are on the opposite side.

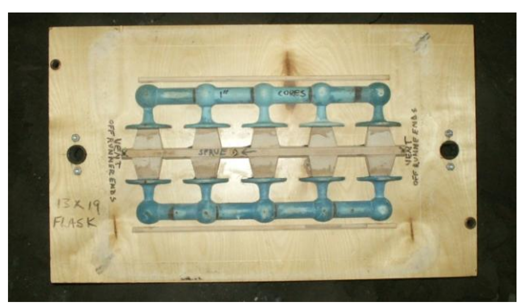

Figure 17- A hand rail match plate that has a ten part yield, with core prints, in-gates and runner mounted on the drag half.

Match plates with patterns on both sides require a very high level of accuracy during assembly to ensure the patterns are properly aligned. One technique to overcome this problem is a solid cast aluminum match plate. The one drawback to this process is the double shrink rate that must be applied, one for the shrinkage occurring during the casting of the aluminum match plate, then the shrinkage during the final casting process. Figure 18 shows one side of this type made to produce a porthole lens frame. Figure 19 shows the opposite side of the same match plate.

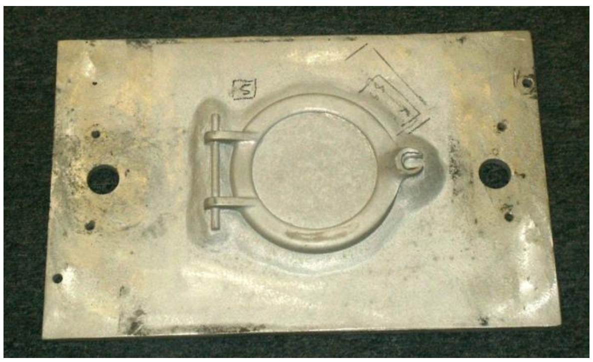

Figure 18– Cast aluminum match plate for porthole lens frame. Note the needed contours on the surface to release properly. The round core print for the hinge pin and the S inside the square is where the sprue will be placed during production.

Figure 19– Opposite side of porthole lens frame match plate. Note the reverse contours, round core print for hinge pin and the black line represent the location of the runner.

To produce quality sand castings there are rules in pattern making that must be followed. They are draft, fillets, radiuses, proper core prints, core boxes, pattern surface finish and most of all the shrink rate of the alloy.

Draft is an angle that is applied to the pattern so that it will release from the sand with relative ease and is in addition to the base dimension of the casting to be produced. On most patterns a draft of 2 to 3 degrees may be all that is needed to facilitate this release, but it can be more on long draws or on core prints to aid in the placement of the finished core. Figure 20 is a cross section of a split pattern showing draft angles added to the base thickness of the desired wall of the finished casting.

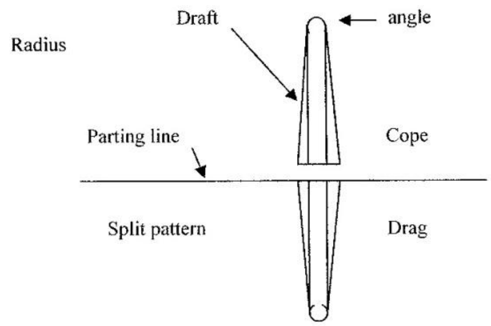

Figure 20- Draft is an essential requirement for sand casting patterns to perform properly.

The need for proper fillets and radiuses cannot be over-stressed. Either being to big or to small, can mean more work in the molding process and/or defects in the casting. As a general rule the fillets should be made with a fillet ball tool that does not exceed a diameter, equal to the thickness of the wall of the joining section and/or not less than the thinnest wall section of the casting. See Figure 21.

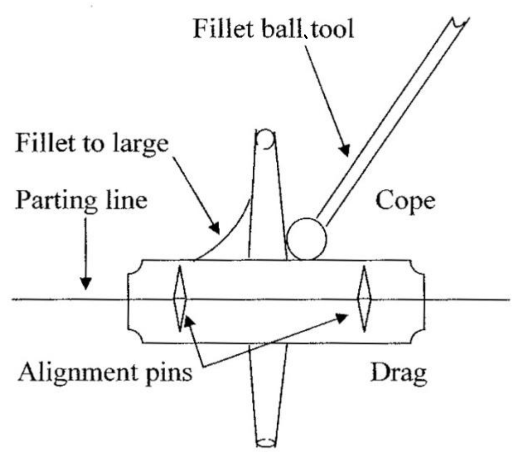

Figure 21– Diameter of ball is the same as the thickness of the joining section.

The use of a fillet ball tool or radius gages will help to maintain the needed consistency throughout the pattern. Some fillet materials are available in pre-made leather and/or wax formed to various sizes. Although one can use any type of filler on hand, as long as the end results are the correct size and shape. The size and shapes are the first function of the fillets; to aid in the release of the pattern.

The second and most important function of the fillet is to eliminate the harsh internal corner of two intersecting surfaces. This is put to the test during the pouring process. When metal, at its proper temperature, is poured into a mold without fillets, there is an internal phenomenon that can happen at these intersections. The turbulence and friction created as the metal flows over these hard corners raises the metal temperature at these points causing hot spots in the sand. As the metal cools, the sand hot spots transfer back to the metal and inhibit the ability of the casting to cool uniformly or directionally. The super heated sand holds the temperature longer, thus cooling last, and forming tears and shrink voids. Fillets will help eliminate the need for extra risers, molding work and/or being plagued with hot tears or shrinkage defects. Figure 22 is a cross section of a mold, feed system and a pattern that has intersections with no fillets.

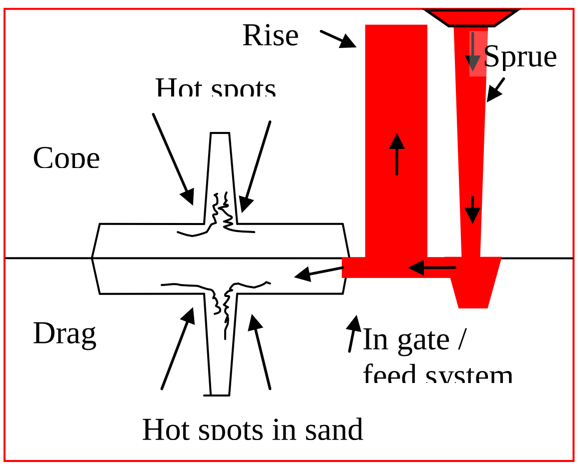

Figure 22– In red is the feed system consisting of the sprue, runner, in-gate and riser. Arrows show flow of metal as mold is filled. The squiggled line denotes turbulence that creates hot spots.

A radius on the edges of the pattern can vary according to desired appearance or to help aid draft in pattern release. When a radius is forming the outside wall of a hollow part care should be taken to maintain an equal wall thickness throughout the part. See Figure 23.

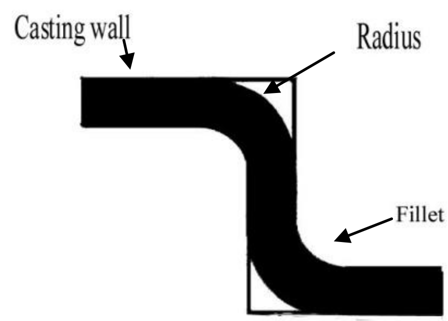

Figure 23– Representation of a casting that maintains a very even wall thickness throughout.

Cores in simple terms are a third party added to the mold. They allow us to put holes through parts, create hollow sections, slots and undercuts in castings that are complex in design. They help reduce weight and can help with directional control of solidification in the casting. Although they add cost to the pattern and molding process, in the end you will have an improved casting with less machining requirements. First, you need to determine if a stock core will work with your pattern. Stock cores are available for most round applications in diameter sizes from ¼" to 12" and varying lengths. See Figure 24 .

Figure 24- Samples of stock cores known as shell cores and produced with a hot box process. Note as the cores get larger they are hollow; thus the name "shell".

If the core shape or requirements for the core are more complex, then the core would be the first step of the pattern process. This is called a core master. See Figure

25. The core master can, in some cases, become part of the finished pattern and will reduce the time and expense of making it twice. When starting the core master, it must include all the same aspects as the finished pattern to achieve the intended results. A parting line, draft, fillets, radiuses, and in the case of large cores, over prints. The core master will have the required core print surface area to suspend it in its position in the mold. Cores that are not held in position properly can float or shift during the pouring process causing rejected parts. I find it better to have more surface area on core prints then risk the latter. Once the core master is finished and coated with a release agent, we can now use a reproduction pattern plastic to cast the core box. Prior to pouring the core box a predetermined surface of the core master will need to be exposed, so that core sand can be rammed or filled into the finished box. See Figure 26. We use Freeman Re-Pro plastic. This is done by fastening the first half of the core master to a flat or surface that conforms to the parting line, then assemble a frame around it to retain the plastic. A lid is fit to cover the frame and is drilled with a hole to ensure that filling was complete. Frame and lid bond to the plastic and become part of the core box. Once the first half has cured, remove it from the parting surface. Place the second half on top and repeat the process. Now that the second half has cured, we rough finish the outside of the core box and drill for alignment pins or dowels prior to removing the core master. Care should be taken when drilling the pin-holes so they are not through the core master. Now with the pins drilled we can de-mold the core master and expose the intended surface for filling with core sand.

Figure 25- Core masters for wire sockets. Left was used to make the core and core box of Figure 2. Right is for the open or forked end socket.

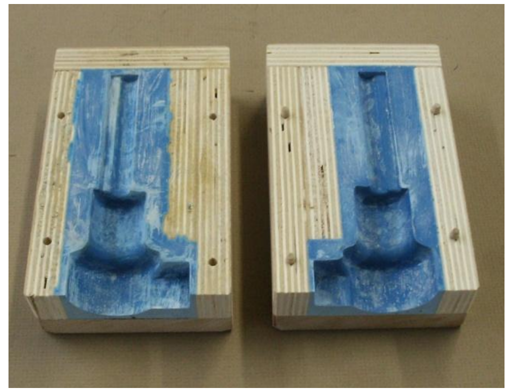

Figure 26- Core box just after removal of core master. Facing end cut open to allow sand to be filled into the box when both halves are clamped together.

Now the core master can be used to build the pattern on or around it. This process ensures the core is a good fit in the core prints. As the process of building or applying the pattern to a core master is finished, we will need to finish the surface of the pattern to a fine uniform smooth surface. One can use a number of different sanding sealers or pattern shellac. We use shellac for most projects and if needed a high gloss enamel over that. In Figure 14 you can see on pattern 181 (Genoa car) the core print is colored in black shellac. This is part of the standard color code for production patterns. The patterns in Figure 15 are used to produce very short runs and they are only finished with a good enamel sanding primer. Figures 16 and 17 show the Re-Pro plastic as it is naturally and only the match plate and feed system are sealed. In Figures 18 and 19 the cast aluminum match plate can be polished to achieve a very smooth casting if needed.

Now the most important rule in pattern making- the shrink rule and how it applies. Shrinkage or contraction of the cooling metal can be explained in three categories.

- First, liquid shrinkage occurs while the metal is cooling as a liquid. This is something that the foundry must deal with directly.
- Second, solidification shrinkage is a significant decrease in volume during solidification. It is one of the causes of shrink voids that can vary from large visible ones to microscopic, and is a direct function of the risers in the feeding system to supply a reserve volume of metal as solidification takes place.
- Third, solid shrinkage or "pattern shrinkage" is the casting showing different dimensions than the pattern. It usually denotes contraction or in some cases expansion in length, width or thickness measured in a straight line. This

shrinkage measurement can only be taken after the casting has cooled to room temperature.

To overcome these challenges shrinkage rulers were devised and can be acquired in lengths for the alloys the patterns are to be cast. They come in 1/10", 1/8", 5/32, 3/16" and ¼" per foot. The use of the proper ruler will be subject to change based on design and even the length of the casting for the alloy and process. This is where input from the foundry is of great value. For general purpose we use 5/32" per foot for aluminum, 3/16" for brass/bronze and for bronze over 24" in length, 1/4" per foot. Figure 27 shows most useful pattern tools.

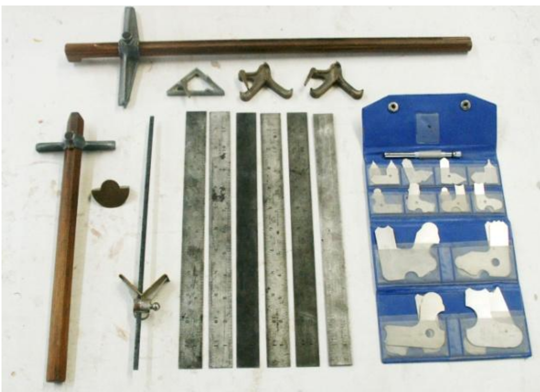

Figure 27– Center are shrink rule; right is radius gage; far left is a match plate scribe, edge finder for dividers and depth/center gage; top is a long match plate scribe, square/45 and canter finders for the rules.

APPLICATION ON THE FOUNDRY FLOOR

As we move to the foundry floor we need to highlight some of the terms used previously to better understand the sand casting process. First all molds are made in flasks, top half being called the "cope" and the bottom being the "drag". Some may have a third center section called the "cheek". See Figure 28.

For molding we will need a "bottoming board" or plate for under the mold, and a "parting board" for loose patterns. Once the mold is finished and flask removed, it will receive a "jacket" and be placed on the pouring floor.

During the molding we will use preformed, "sprues", "runners", "in-gates" and "risers" to aid with creating the feed system if we are not using a match plated pattern. Molding can take place on a molding bench, a squeeze-jolt machine or floor. Figure 29 shows a flask on a squeeze-jolt machine.

Figure 28- Front is a cope and drag stripper flask, Note guide pins on the outside of the flask. In the back is a cope and drag with a cheek center.

Figure 29– Portable squeeze jolt machine with flask on the compaction table.

Before molding, sand prep must take place. Proper mulling and/or aeration to ensure that both binders and water levels are correct- this is the key to any successful casting. To start the molding process with a loose pattern, a parting board is slipped into the flask between the cope and drag. Then the flask is inverted with the drag side up, allowing us to place the drag half of the pattern inside the flask with the runner, in-gate or gates as needed. See Figure 30. The patterns, runner etc. are lightly coated with a dry parting dust called "partina", and then we do a face coat of finely screened "riddled" sand. After the patterns are completely covered we back fill the flask with aerated sand to a level above the rim of the flask (mounded). Now the jolting process starts, (the pneumatic squeeze-jolt machine jolts/compacts the sand). Next we proceed with any hand ramming necessary to tighten the sand around the patterns. We finish the drag by adding any needed sand and a final compression of the mold with a squeezer plate. The drag is then "struck" (scraped) level to the rim of the flask with a striker bar to ensure that it sits flat on its bottoming board. Now that the drag is rammed up, we flip the flask back to an upright position on its bottoming board and remove the parting board. We proceed by removing any lose sand, then placing the cope portion of the pattern on top of the exposed drag parting face of the pattern, placing the sprue, riser and any needed vents. Repeat the face coating with riddled sand, back fill and jolt. Hand ramming is done to finish this side of the mold on most short run parts. Once the ramming is complete, the cope is struck off to the level of the flask, cleaned and the sprue, riser, and vent forms are removed. Now we split the flask by lifting the cope off the drag, facilitated by the flask pins that keep the two halves in alignment during the molding. With the parting line now exposed we can clean, remove runner, in-gates and then the patterns from both the cope and drag. At this point it is crucial to pay close attention to the sprue, risers and in-gates to ensure they are of proper size, placement and are clean without loose sand or obstructions that may impede the flow or become entrapped in the metal. Now that the cope and drag are ready to close any needed cores will be placed into the mold's drag, making sure they fit properly. See Figure 31. The flask alignment pins again facilitate closing the mold; once closed the flask is removed and a jacket is placed around the mold for support during pouring. Figure 32 is the cope just prior to closing the mold. Molds are then moved onto the pouring floor. After being poured, they are allowed to cool and broken out of the sand to reveal the castings. Sand is reprocessed and the casting processes are repeated. See Figure 33.

Figure 30– Patterns placed in drag half of the flask with runner.

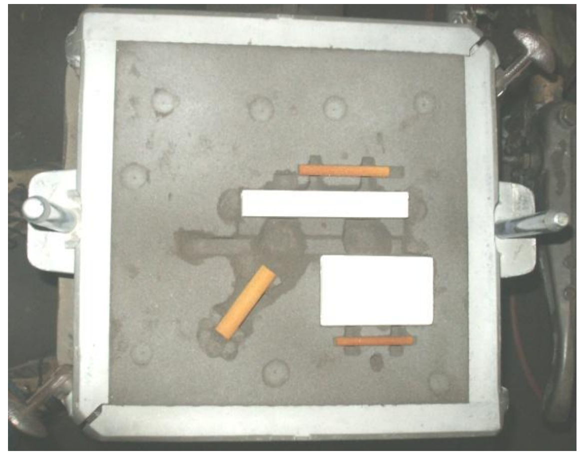

Figure 31– Core placed in the drag and ready to close flask.

Figure 32– The cope ready to place on the drag; sprue on left and risers in the center.

Figure 33- All of the parts of a Genoa track car still attached to the feed system, sprue to the far left, two center risers and attaching in-gates. Note that the cores are burnt, but still intact.

FINISHING THE CASTING

This starts with the cleaning of the castings with their gates, runners, risers and sprues attached. After blast cleaning, the castings are cut free of the feed system and excess material returned for re-melt. The castings are processed by first removing gates and parting lines with hard grinding wheels, taking care not to grind beyond the finished surface levels. Then for most castings only blending with sanding discs will be required before being tumbled prior to machining. If the mold is done with proper care, the casting surface finish should have a texture close to 100 grit sand paper or better. It is important to use a sanding disk that best matches the cast surface during the blending process. Once castings are returned from the machining process they can be de-burred and prepped for the final finish. If a high bright polish is required, additional surface finishing may be performed with various products and/or tumbling.

MACHINING AND INSPECTION OF THE FINISHED PART

Castings can present some challenges to overcome during the machining process with all the previously mentioned requirements such as draft, fillets, radiuses, and cores. They can be odd in shape and may not have any truly flat surface from which to start. So from the beginning, design-for- machining requirements should be discussed and incorporated when the pattern is made. The inclusion of removable bosses, tangs, pads to facilitate set up are a great time saver. Parts that can be spun on a lathe will also save time. For those requiring mill-work, they will benefit from additions to the patterns to form parallel sides or data points to level or hold the casting to the mill table. In Figure 33 parts of a Genoa track car, the car body is cast with a T-slot core, but care was taken not to disturb the parallel side of the casting so that no grinding will take place on them prior to the milling operation. This is where they will be held in the fixture for slot clean up; this is the best repeatable surface. The roller can be held in the chuck of the lathe on the outer edges, bored and then placed on a mandrel for external machining. The car swivel only requires reaming the cored holes and drilling in the location of the pre-marked casting. This is seen as a dimple in the casting that was properly placed on the pattern. Good machining starts with good castings and they require good accurate patterns. See Figures 34 and 35 for examples of complex finished machined parts. Once all parts are finished in the machine shop they are returned to the finishing room for de-burring, polishing or the required surface treatment.

Figure 34- Windlass wildcat and gypsy made as replacement for M/V CANGARDA.

Figure 35- Assembly and chain fit in wildcat.

When castings are in machining we can penetrate their surface in ways that allow us to visually inspect the internal structure for flaws or other defects. Drilling holes, cutting slots, or machining can tell us if the integrity of the cast is sound. If dross, inclusions, gas voids, shrink voids or external surface defects are found, then the parts are rejected.

All testing to verify breaking strengths or to fit into a class or grade are done by an outside independent source.

CONCLUSION

This paper is in no way in-depth enough that one can get into the art of casting and all the nuances of each step. We produce such a wide range of castings that to include their individual requirements would only cloud the basics needed to begin asking informed questions. To get the level of success that you desire will be based on your own willingness to learn and patience to overcome any of the obstacles that are presented.

Remember to design to the rule "form follows function" and then for the best economics. Get input early and often. Remember that there is always the human factor to overcome, what I see, may not be what you see.

Casting is not for everyone, but castings are in every part of our lives and so the better we understand how they are made one can gain an appreciation for the craft.

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127 Industry Blvd.
Irwin PA 15642

American Foundry Society
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ABOUT THE AUTHOR:

M/V Catalyst circa 1964 San Diego CA. Pete, Paul, David, and Patrick left to right.

Peter Langley today.

Pete Langley has been sailing and cruising since the age of 3; by age 20 almost 70,000 miles at sea. From family power yachts to sailing skiffs and even a stint on commercial fishing vessels: an accomplished seagoing sailor on any size vessel. The family currently owns the six-meter INDIAN SCOUT US 66, the 5.5-meter COMPOSITION US 65, and a William Garden designed cutter PACIFIC TRADER built by Hope and Langley launched in 1976. Pete has taken his knowledge of the sea, and the fittings necessary for safe passage to the foundry. (Form follows function, and with Pete's artful touch is a beautiful working piece of hardware.) Many mentors and old time mariners have helped hone Pete's skills. Pete is the founder and owner of Port Townsend Foundry LLC since the early 1980's.