STEEL FOUNDERS' SOCIETY OF AMERICA

2021- Thor's Hammer Contest

Mjölnir Team

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KENT STATE UNIVERSITY

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1.0 OVERVIEW

Thor’s Hammer, Mjölnir, a thing of legend. Forged by the dwarfs of Nidavellir, enchanted by the allfather Odin, steeped in Norse mythology, and quite literally drawn to the champion of Asgard, Thor himself. Design and cast a modern day living representation of this hammer was the challenge placed on those who choose to step up and accept the gauntlet that Steel Founders’ Society of America (SFSA) tossed out into the ether. The following pages contain the journey of one such team from Kent State University that took up this challenge. They toiled away into the wee hours of many nights, juggling traditional coursework, personal commitments, an actual pandemic, and mortal limitations. They poured blood, sweat and a few tears into the making of this hammer channeling their own Norse ancestors in the hopes that you, dear reader, would deem them and their hammer…….worthy.

2.0 HAMMER DESIGN

To create a hammer such as requested, one must consider a multitude of things. This section breaks down the process specific to the concept, form, and development of our submission for the 2021 SFSA competition.

2.1 Competition Constraints

Per the SFSA specifications set forth, the fully finished competition submission was not to exceed 6 pounds or 20 inches in any orientation. As far as guidelines for design go this is fairly barebones in terms of aesthetic and functional prioritization. The first design issue involved the creating a hammer befitting a god; following that was how to make this abstract idea fit within the guidelines. How much weight do we allocate to the cast hammer, the handle and to any accoutrement that went with the final product such as leatherworking or engraving?

Due to the finite size limitations of the junction between the casting and the handle, it was determined that the first step was to decide on a handle that would dictate what overall shape the casting would take. Placing an order with McMaster-Carr, we purchased four generic hammer handles to compare size and lengths to utilize as scaling aids: two at 16 inches and two at 18 inches. These lengths were chosen so as to provide the longest fulcrum possible without violating the contest specifications provided by SFSA. The chosen handle drove the design process that the cast component would take as far as weight allocation, while indirectly influencing the overall aesthetic. Utilizing an excel based calculator that was developed by the team captain, we laid out several options as to what could be done with handles of given lengths and how much of the weight budget would be allocated towards other features. This final decision being to use a modified 16” handle, cut to 14” that would work with our inspirational design.

2.2 Inspiration

Our team focused the design to be more true to the Norse mythology, specifically inspired from the painting by Mårten Eskil Winge titled "Thor's fight with the Giants" (1872) depicting the thunder god triumphant upon his goat drawn chariot, wielding the mighty Mjölnir above his head to strike down the enemies of Asgard.

Figure 1: *Thor's Fight the Giants (Winge, 1872)*

The decision was made to utilize a shortened handle of 14 inches to stay true to this image, noting that the hammer is being wielded with one hand. A shorter length offers an improved mechanical advantage to the user's swing in a combat setting. This is primarily manifested as a slightly "too heavy" hammer head with a handle just short of the sweet spot for a lever. Selecting this length, along with some rough weight estimations, meant the user's grip would not fatigue during extended usage while still providing a hefty implement to deliver significant force to follow through a swing. Additionally this design honored the original legend; depicting Eitri and Bokkr forging the handle for a competition to win favor from the Asgardians.

During the manufacturing process, Loki interferes and causes a defect which breaks the handle resulting in Mjölnir to be a one handed weapon instead of the intended two handed warhammer. In conclusion: sizing the cast hammer head to be slightly heavier while making the handle to be slightly shorter than is customary is more true to the Norse legend, while simultaneously rendering a formidable implement that benefits the end user.

2.3 Practical Elements

Utilizing design elements derived from the Winge painting, the form chosen by the team draws geometry from two familiar shapes. First, an octagonal Bourbon glass to pay homage to the squared faces of the hammer depicted in the painting as well as the popular Marvel movies. And secondly, the winged style inverted hammer historically and commonly found used for pendant style jewelry. The octagonal loft concept was chosen to maximize the possible strike face area should the wielder roll their wrist due to fatigue or poor technique. This feature allows the user to be more cavalier in the angle of their attack without having to pay much attention to the possibility of striking unevenly and rolling their strike. In a typical round faced hammer design this nose heavy blow will result in a glancing shot that will have minimum impact force applied to the desired target, whereas the hard corners of the octagonal face will plant into the target. Furthermore, in a combat setting such a glancing strike will likely throw the wielder off balance and open them up to the possibility of a counterattack. This requires that a more accommodating design was a necessity for the hammer faces of our hammer casting.

2.4 CAD Modeling

To begin putting life to our concept and flesh out the above mentioned design we moved to 3D rendering models utilizing the Inventor software program. This aided with the generation of our castings geometric layout.

The octagonal shape chosen for the hammers faces seen in Figure 2, graces a wider angle for incoming strikes that would increase the magnitude of force applied by reducing the surface area of contact between hammerhead and target. Combining the octagonal face with a large radius “crown” further increases the possible angles of strikes that will hit true.

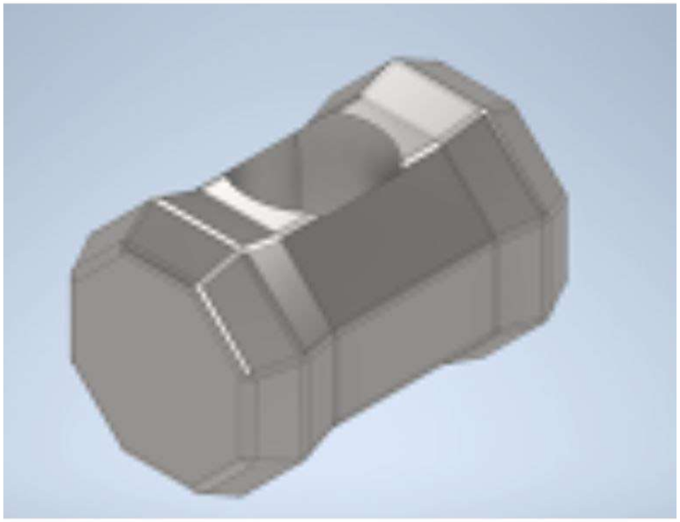


Figure 2: *Octagonal “Bourbon glass” design, early iteration of group CAD work*

The winged shape that we incorporated into our design involved the idea of involute curves along the top and bottom of the hammer's side profile. The corresponding “ribs” located at the top of Figure 3 bring more of the hammer’s weight closer to the outer edge of its swing arc yielding a more efficient mechanical advantage for the wielder to swing faster without being thrown off balance. When combined with the crowning technique as previously described, the ease of use for the wielder increases exponentially without being a detriment to the amount of force required to swing.

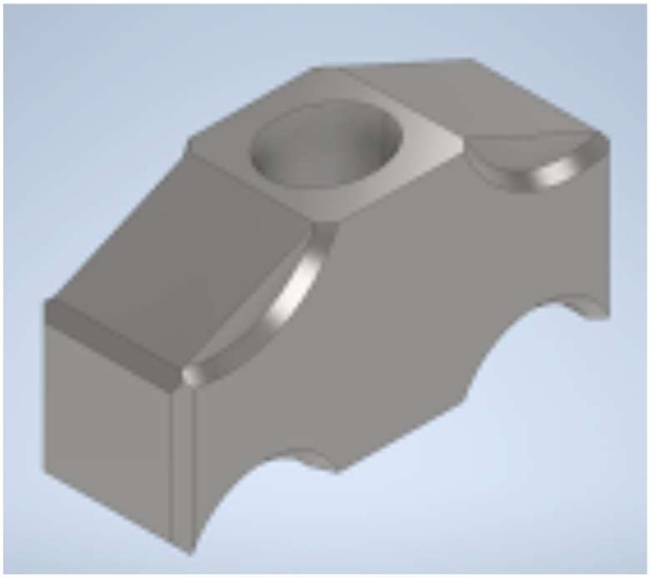


Figure 3: *Opposing curves “ribbed” design, early iteration of group CAD work*

Our team felt both the octagonal face and the involute curvature “ribs” married quite nicely during our initial design meetings and paid proper homage to both the Norse mythology and the specific Thor’s hammers that we wanted to achieve for this competition, as shown in Figure 4.

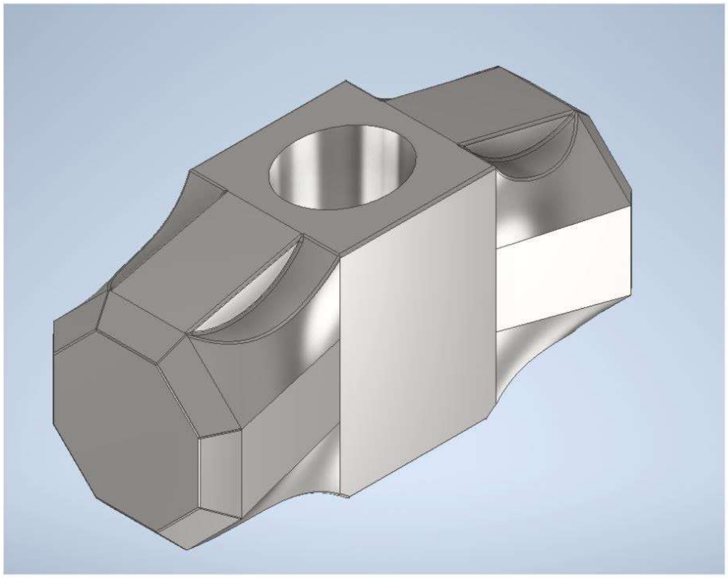


Figure 4: *Finalized CAD design, merging the opposing arches design with the octagonal faces of the “Bourbon glass” design*

The amalgamation of these two designs culminated in estimations that the final casting would weigh in at 4.875 pounds based on the CAD model. Adding in the approximate handle weight this left approximately 1 pound of wiggle room to go towards aesthetic additives such as leatherwork and decorative embellishments without compromising the intended optimization for the end user. Any further removal of material for aesthetic engravings would reduce the weight of the finished casting, beyond our acceptable weight goal. A collaborated effort to estimate the difference of mass led the team to calculate approximately half a pound of metal loss during the finishing processes. This meant the final product would weigh in at approximately 4.25 pounds. Ultimately, this estimation proved to be lacking as the finished hammer head casting weighs in at 4.04 pounds; meaning that the total material removed for surface finish was well over three quarters of a pound.

The elegance in our design application is that it is NOT a massive two handed warhammer, but a one handed weapon that can be swung with ease due to the weight distribution in relation to the 14 inch handle. The advent of the opposing parabolas when viewed from the side as in Figure 5, visually cancelled which resulted in the finished casting to be more aesthetically balanced. The 8/10ths inch wide rib brought most of the castings weight to the furthest point of the swing, which allows for a greater striking force without slowing down the wielder.

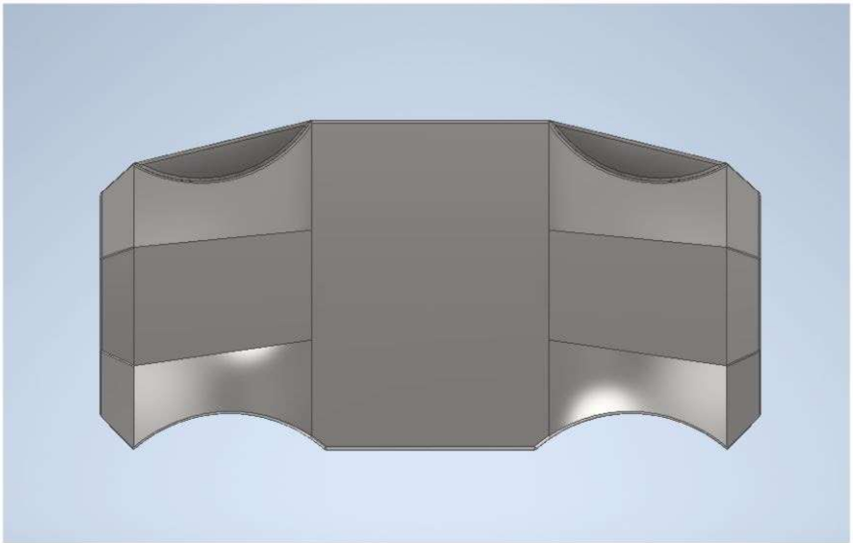


Figure 5: *Finalized CAD design side view, notice the curves visually cancel while the upper half retains the blocky “ribs”*

3.0 MAGMASOFT

Once the final design of the hammer was agreed upon, additional systems were necessary to bring this to fruition. We proceeded to further hone our design by moving to MAGMASOFT simulations. After much discussion with our Faculty Advisor, it was determined that utilization of 3D sand printed molds would allow for placement of a core where the handle hole exists to eliminate the need to extract copious amounts of a durable steel from the casting. This left us with the need to add a gating system, chills and risers to the renderings we had developed in Inventor. Through trial and error, it took 31 iterations of casting design in MAGMASOFT to finally get a product that would generate a quality casting. Figure 6 shows the final casting soundness; areas in yellow depict locations where porosity due to shrinkage would show up.

Figure 6: *MAGMASOFT simulation rendering of the general soundness of the casting and gating system with a unified scale gradient*

From this finalized cavity simulation, a negative mold .ipt file was generated which was then exported as an .stl extraction file. This exported file was then used as an input for the sand mold machines at Humtown Additive, a branch of Humtown Products, located near the Kent State University Material Lab.

3.1 Gating

To terminate the flow of open air, an ovoid cross section shape was selected for our gating system. Typically steel gating designs have a rectangular cross section from the downsprue to the casting, which is intended to catch turbulence in the corners and reduce pattern shrinkage. While this is the standard doctrine per AFS literature, there was not a MAGMASOFT simulation generated which did not show a detrimental spike in velocity which would result in a porous casting. Under careful monitoring by the team Advisor, a simulation was generated with a non-traditional form factor. After several iterations for verification of the model's fidelity, our team elected to implement this casting method. The ovoid cross section, as shown in Figure 7, with the long axis being upright provided a greater volume of area to absorb the velocity generated from metal moving from the pouring basin through the downsprue. The inclusion of a flowoff allowed the liquid metal to decelerate by equalizing the force against ambient air pressure while it was still inside the runner. With the addition of the canted ingates there was no metal entering the cavity before the runner was completely filled, having soaked up the initial surge of liquid metal into the flowoff.

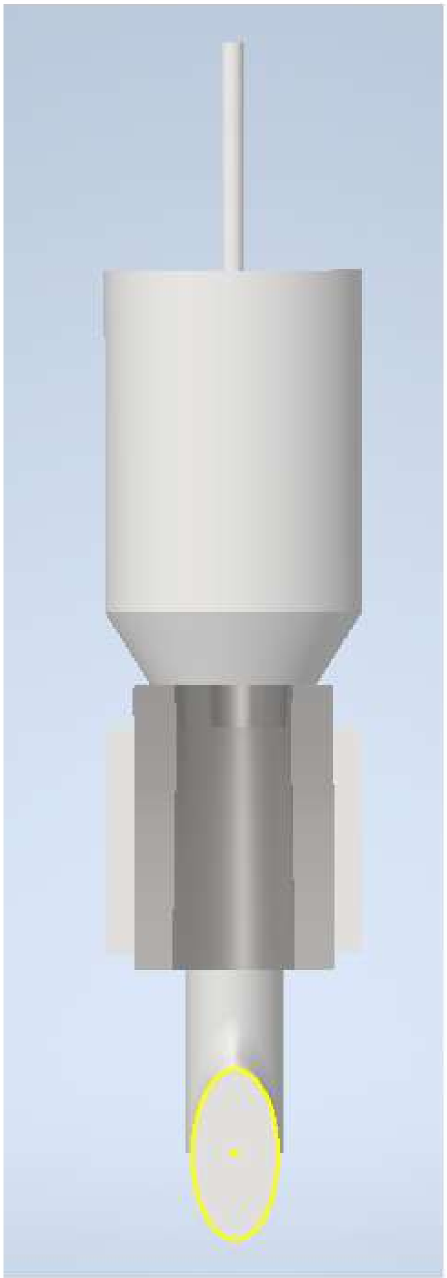


Figure 7: *Final CAD Model, cross section of ovoid Gating system*

3.2 Riser

In designing the risers the first constraint was guided by two driving factors: a need to feed the casting in an effort to mitigate shrinkage and to not interfere with any of the geometry that defines the casting form. In conjunction with the placement of chills and the effects of the cooled gates acting in the same fashion, the risers are the last to solidify. The secondary constraint lies on the other end of the spectrum where the risers get to be such a large thermal mass that it can impact the binder holding the sand mold together. This is known as sand burn-on, and was the primary concern with the riser placement on the hammer's involute undercut. Figure 8 shows the sand burn-on magnitude adjusted to the MAGMASOFT unified gradient scale, indicating a concentration located between the risers and the hammer head. This is due to the exposed nature of the sand mold at this location, where the geometry creates a situation that sand is getting baked from two sides and burning into the liquid metal as it cools. This was mitigated by grinding the final casting and scaling the entire involute shape after pouring.

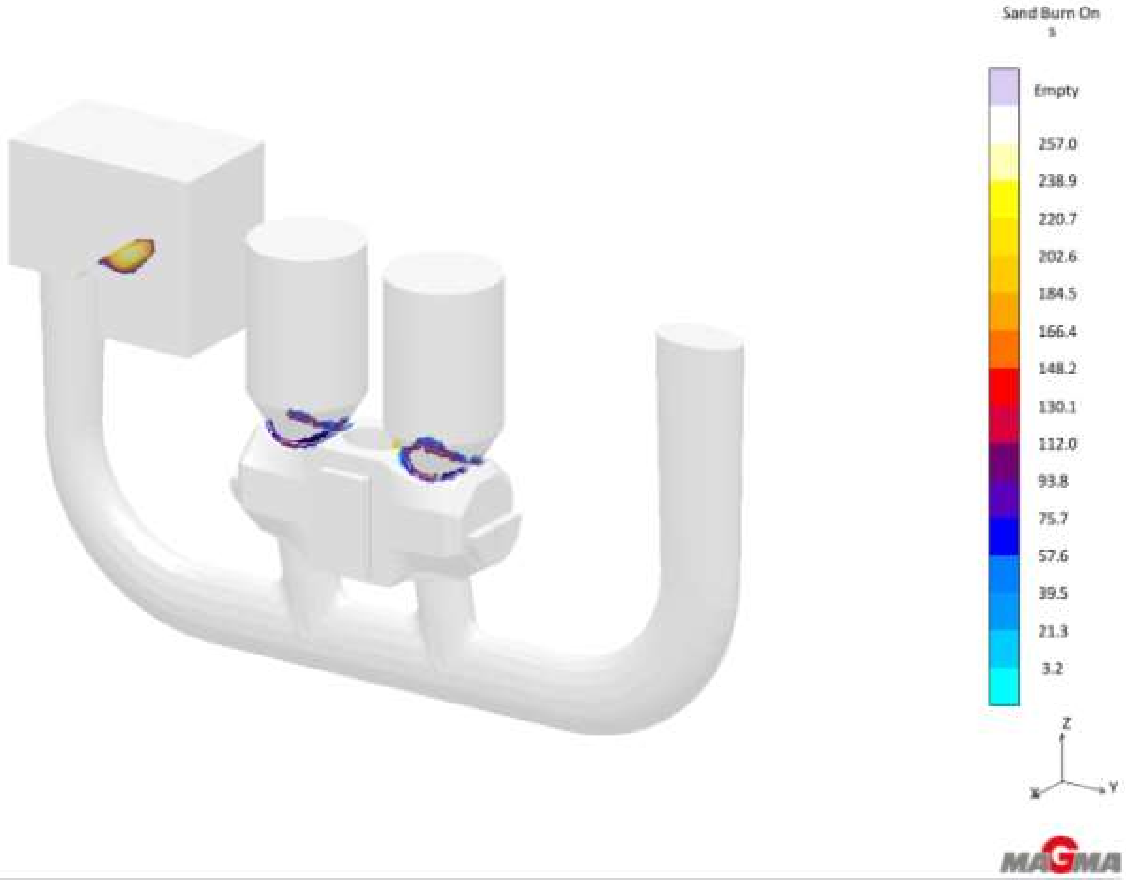


Figure 8: *MAGMASOFT expected sand burn on*

3.3 Chills

There are four areas where chills were implemented; the motivation for this placement was that all chills were oriented in such a way as to drive the advancing cold front towards the risers. The theory behind directional chilling is that the last part of a casting to solidify must be the risers, which allows time to feed the casting and reduce shrinkage. This was intended to effectively cut the casting in half while cooling, meaning that porosity would not occur in the thinnest part of the heads geometry.

The proper application of chills should yield a mechanically solid casting free of pinholes and cavities. There were two forms that the hammer's chills took to advance the goal of a good casting: quarter rounds and rectangular. The quarter round chills were cut as 1/10th inch wafers from 1.5 inch diameter round stock A36 steel. The stock was then cut into quarter wedges that each measured approximately 0.75 inches in radius. Two of these quarter round chills would be applied to both faces of Mjolnir on either side of the mold's parting line. The motivation for this placement being to drive the advancing solidification front from the bottom most corners of the casting upwards. Rectangular chills measuring 1 inch by 2 inches by 0.25 inches were applied to both sides of the casting cavity with the intention to chill the thin walls on either side of the handle cavity, thus resulting in the casting being cut in half during the cooling process, as shown in Figure 9.

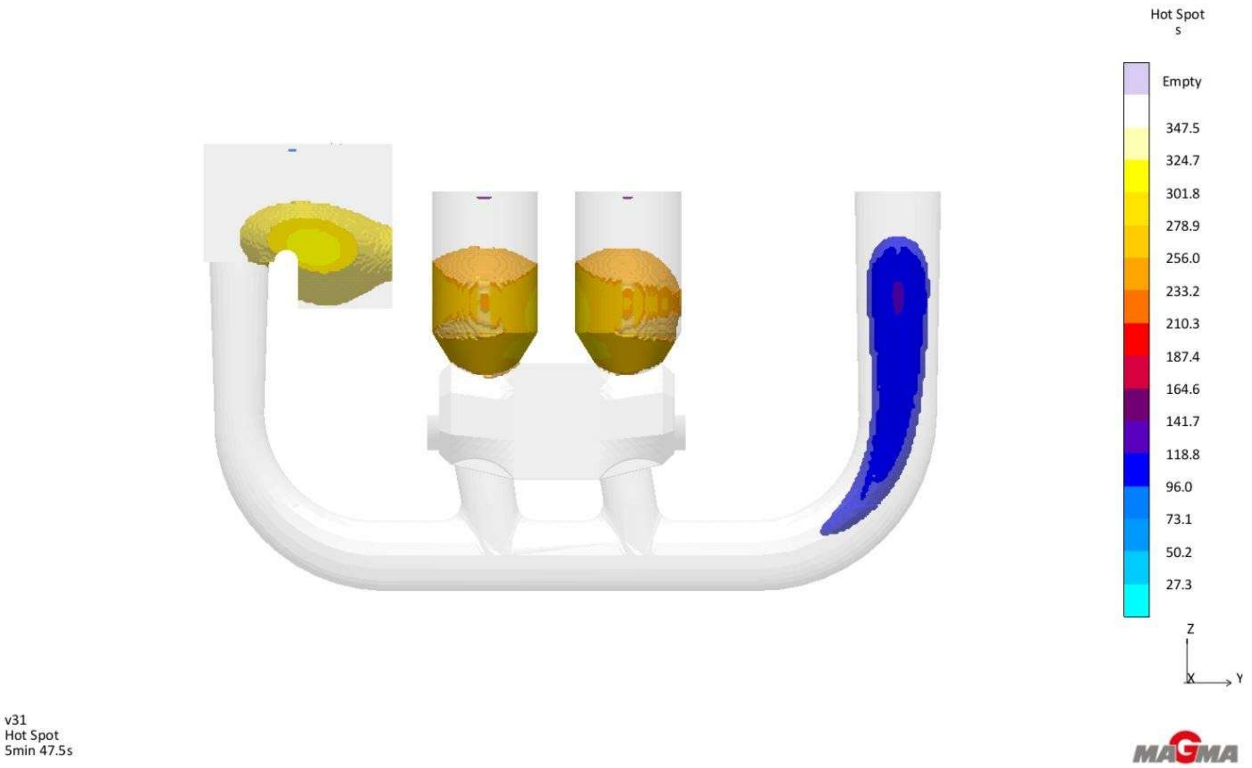


Figure 9: *Finalized CAD design of gating system in MAGMASOFT, depicting hot spot location 5 minutes forty seconds after casting*

The preparation and placement of chills facilitated the creation of the highest quality casting that could be produced by this student team. A great deal of care was taken to determine the best placement for designating chills in the CAD models, which translated to the final design of our hammer mold.

3.4 Shrinkage

The MAGMASOFT simulation indicated that pattern shrinkage would not be detrimental to the final casting. Most of the expected porosity due to shrinkage would be cut off in the risers and the gates due to the application of the chills. This would contribute to a mechanically solid mass of metal that would be easier to finish and perform better in competition stress testing.

3.5 Metal Flow

As with every casting, the speed at which liquid metal enters the cavity plays a dramatic role in the fidelity of the final product. The ovoid gating was designed to depressurize the stream of molten steel and allow adequate room for the rush of mass to decelerate before entering the mission critical portions of the mold. Figures 10-13 show the liquid metal entering the casting; The color correlation is a unified scalar representation which visually depicts how great the velocity is at different points during the pour.

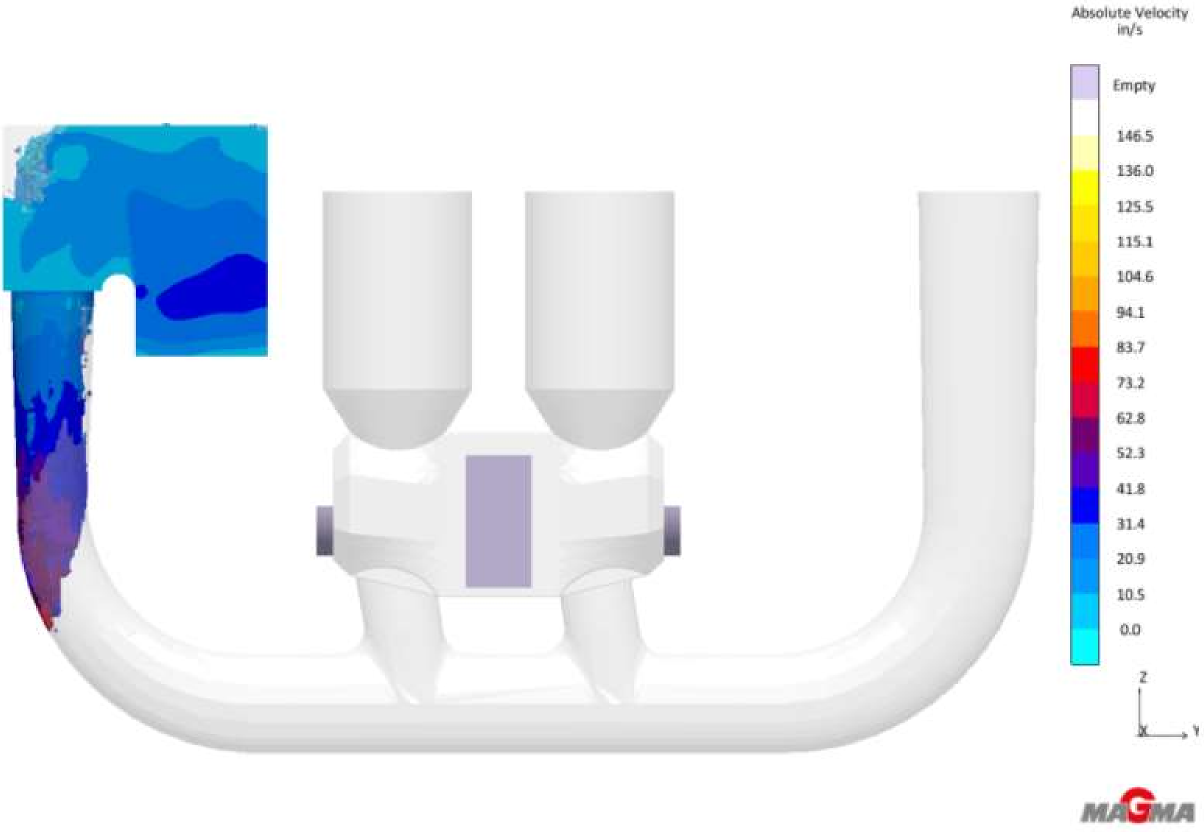


Figure 10: *Initial entry of molten steel into casting*

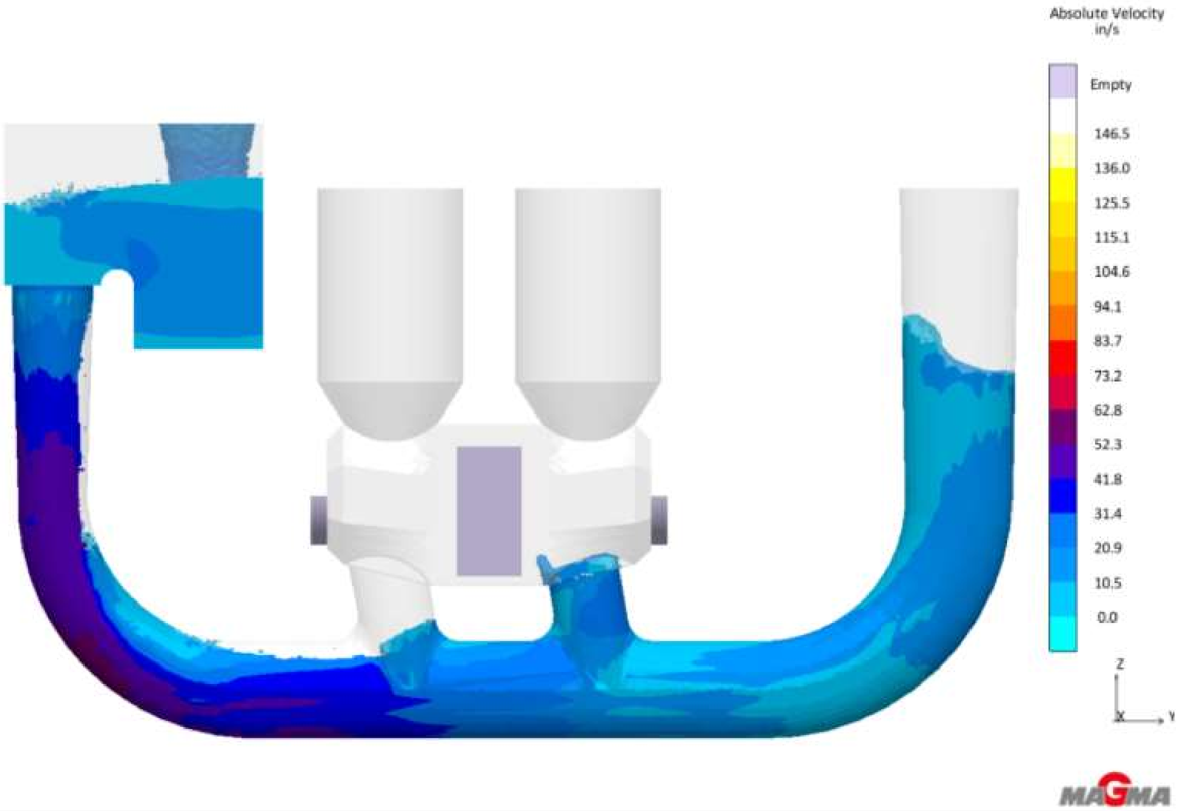


Figure 11: *Flow off absorbed initial velocity, gates beginning to backfill from equalizing pressure driven up the slanted entrance.*

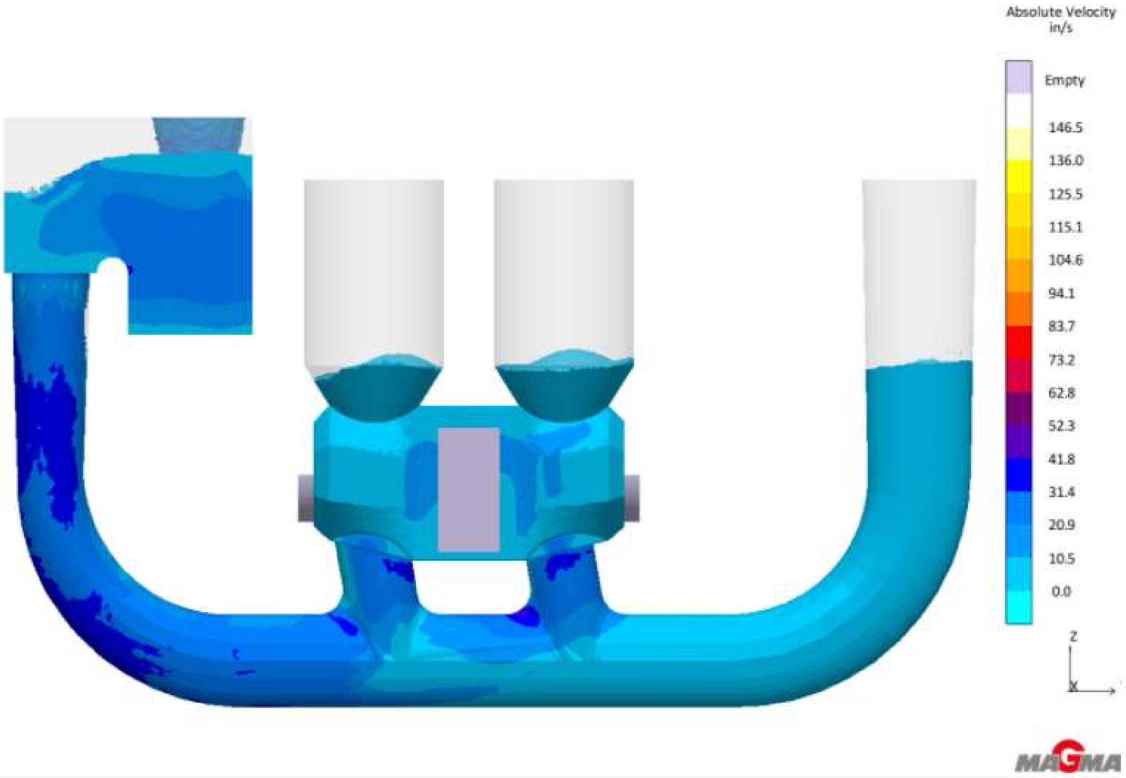


Figure 12: *Flow off equalizing pressure with the height of the Risers, indicating that liquid metal is still entering the cavity in a controlled manner*

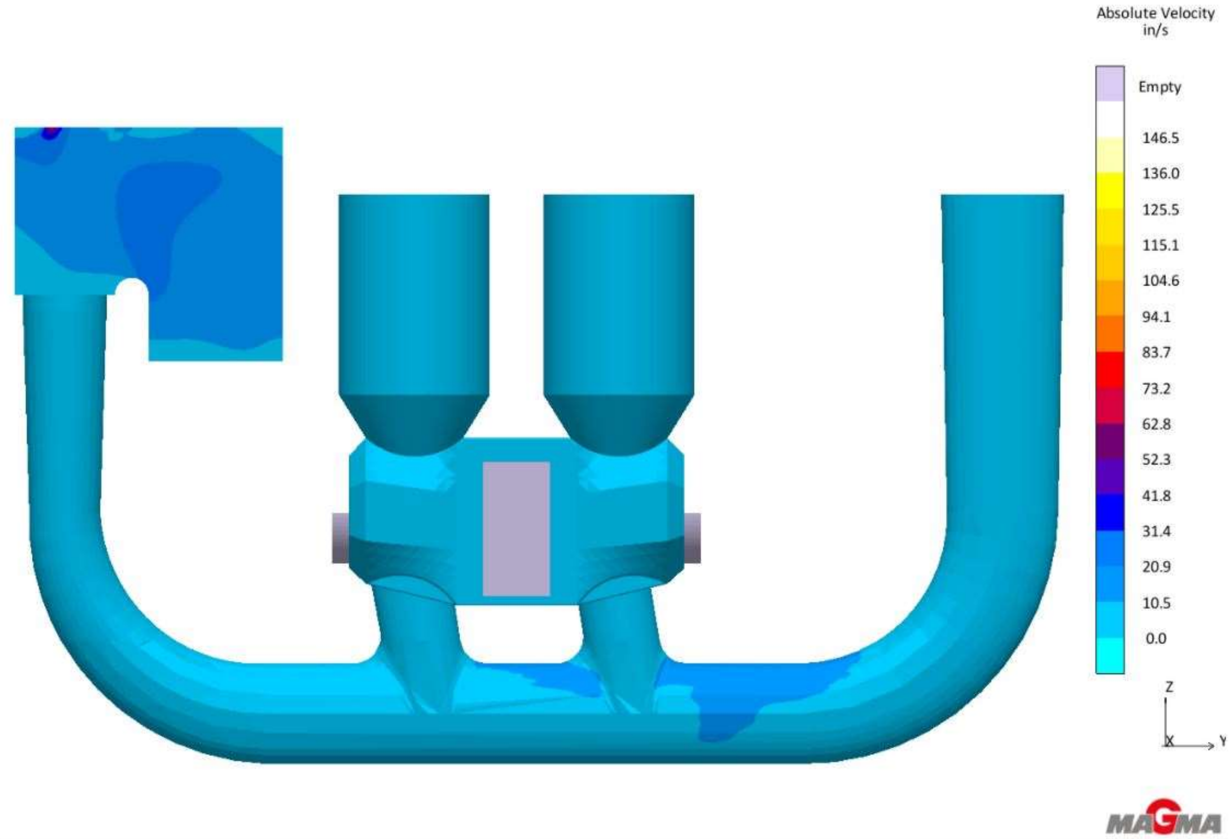
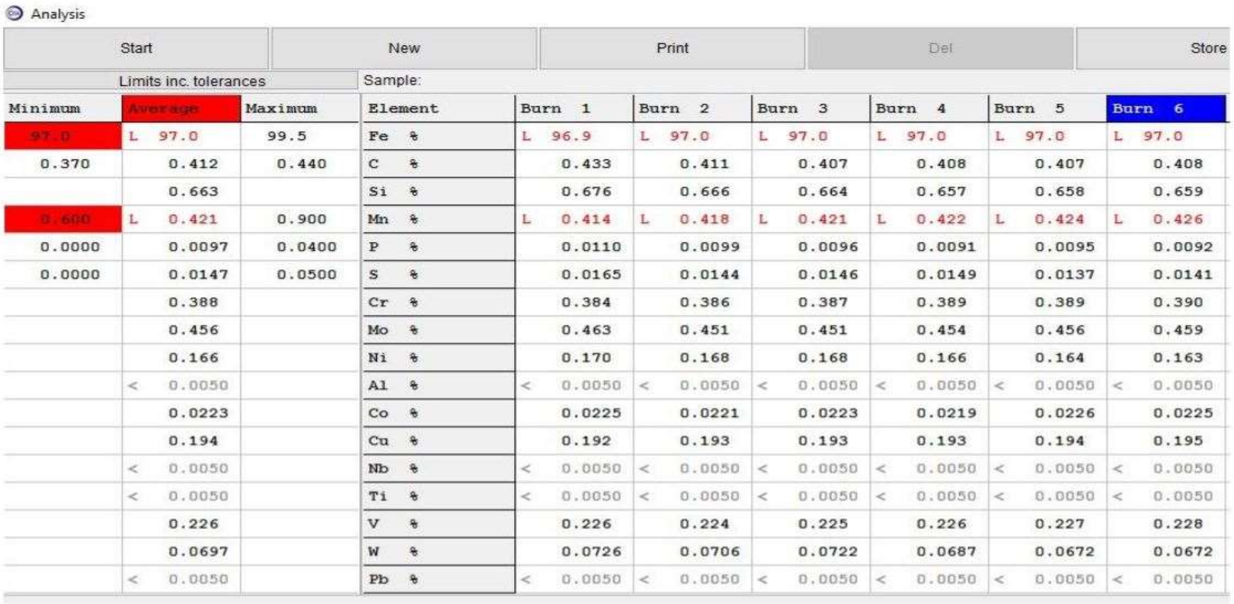


Figure 13: *Final stage of the pouring sequence where the entire mold cavity is filled*

4.0 METAL SPECIFICATIONS

Utilizing the knowledge of our Faculty Advisor's previous experience in the Steel Foundry Industry, we planned and were able to successfully implement a 1060 Steel alloy that could be weld-repaired and hand finished as needed. In the effort of staying on schedule with the SFSA's timeline for proof of casting, it was in our best interest to keep the alloying work simple and straightforward once the hammer got to the casting stage.

To achieve this we started with seven foot lengths of 9260 steel bar stock that were cut to six and four inch lengths to fit into the furnace. Further, carbon would be added to change this base steel alloy into 1060 steel which would be augmented with a high Manganese weld stock applied to the faces. This welded Manganese face would then be ground back in the crowning phase to give the rounded strike face desired. With the advantage of the in-house foundry offered at Kent State University, our team utilized the 100 pound capacity steel furnace; which had been freshly relined with a new refractory liner. In addition, we utilized the Oxford Instruments spark spectrometer located in Kent State University's Materials Lab. This allowed our team to confirm our own alloy creation, as shown in Figure 14, was correct before pouring and potentially rendering a mold unusable and eliminating one of our working castings.



Minimum	Average	Maximum	Element	Burn 1	Burn 2	Burn 3	Burn 4	Burn 5	Burn 6
97.0	L 97.0	99.5	Fe %	L 96.9	L 97.0	L 97.0	L 97.0	L 97.0	L 97.0
0.370	0.412	0.440	C %	0.433	0.411	0.407	0.408	0.407	0.408
	0.663		Si %	0.676	0.666	0.664	0.657	0.658	0.659
0.600	L 0.421	0.900	Mn %	L 0.414	L 0.418	L 0.421	L 0.422	L 0.424	L 0.426
0.0000	0.0097	0.0400	P %	0.0110	0.0099	0.0096	0.0091	0.0095	0.0092
0.0000	0.0147	0.0500	S %	0.0165	0.0144	0.0146	0.0149	0.0137	0.0141
	0.388		Cr %	0.384	0.386	0.387	0.389	0.389	0.390
	0.456		Mo %	0.463	0.451	0.451	0.454	0.456	0.459
	0.166		Ni %	0.170	0.168	0.168	0.166	0.164	0.163
	< 0.0050		Al %	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050
	0.0223		Co %	0.0225	0.0221	0.0223	0.0219	0.0226	0.0225
	0.194		Cu %	0.192	0.193	0.193	0.193	0.194	0.195
	< 0.0050		Nb %	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050
	< 0.0050		Ti %	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050
	0.226		V %	0.226	0.224	0.225	0.226	0.227	0.228
	0.0697		W %	0.0726	0.0706	0.0722	0.0687	0.0672	0.0672
	< 0.0050		Pb %	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050	< 0.0050

Figure 14: *Spectrometer results from in-house testing*

There was no heat treating applied to the 1060 steel alloy for a very specific reason: face hardening was done through means of welding Manganese rods by changing the polarity of the welding unit so as to direct heat into the workpiece. Reversing the polarity of the welder had the additional benefit of a mild heat treat to the casting behind the Manganese hard face. This saved an unnecessary step while simultaneously improving the hammer's hardness.

5.0 MOLDING THE HAMMER

The Ajax Tocco furnace available to students at Kent State University through the Materials Lab was the primary advantage granted to our team and a major reason that we did not have a partner foundry. This lab provides an opportunity for hands-on learning about what is required to cast steel in a safe manner. With all the design elements and simulations complete, the metal recipe decided, all that was left was to pour liquid metal into shape and bring our concept to life.

5.1 Furnace Maintenance

All equipment requires regular maintenance regardless of application or scale. In the case of the Materials Lab steel furnace this involved tearing out and re-lining the refractory insert. This was carried out as a preliminary step; a safety factor, required for the type of induction furnace used. Inside of the furnace containment walls are the inductor coils which heat the metal; these water tubes circulate water throughout the furnace as a way to keep the mechanical parts cold during operation. Were the water to not be pumped in during operation the furnace container would melt, which would result in catastrophic damage to persons and property as 3000℉ steel spills everywhere. Not only would this be a hazard to the operators, but the water tubes would degrade and introduce water into the mix resulting in almost instantaneous sublimation and gaseous expansion. In due form, the 100 pound capacity steel furnace would turn into a claymore resulting in the death of the hydraulics operator, casting operators and anyone within a 30 foot radius, not to mention cause substantial structural damage to the building.

In an effort to avoid such a disastrous event, our Advisor mandated that no steel would be poured until a successful tear-out and re-lining was carried out by our team. With the aid of a pneumatic chisel, team members were efficiently able to remove the liner and all the expired refractory material. Following that, the cavity was airbrushed clean. Then began the rebuilding stage, wherein MgO bedding was packed around the new refractory crucible to insulate the aforementioned induction coils. The final step to the repair process was applying a rammed refractory top cap and spout and allowing time for it to cure thus preventing crack development after the first heat. Unfortunately one day only contains 24 hours; so the safe choice to undergo this rebuild pushed our plans to pour back by two days.

5.2 Metal/Mold Preparation & Furnace Charging

As mentioned in section 4.0, the starting metal was 9260 bar stock that had to be cut down so as to fit into the induction furnace. In order for solid metal to raise temperature efficiently, an understanding of how induced currents cause material to vibrate and generate heat to the point of melting is necessary. This process is facilitated by positioning any material that is being induced perpendicular to the induction field that circles the crucible.

In the lab's furnace, the most efficient setup is an alternating "Lincoln Log" style stack which allows the coiled inductor to induce current in every piece of bar stock evenly. This is shown in Figure 15 which is a top down view of the steel furnace filled with the 60 pounds of 9260 steel bar stock that had been cut down to six and four inch lengths. In the bottom of this stack is the necessary Carbon additives; it was imperative that any additives be placed in the bottom of the furnace allowing melting metal to drip down and mix. Were we to simply throw Carbon additive on top of the molten melt, the majority of the additive would simply burn off before it had the chance to emulsify. This would result in an alloy that had not been calculated before the pour and thus yield a casting that was not the intended 1060 steel alloy.

Figure 15: *Top down view of the Ajax Tocco 100 pound capacity furnace charged with 60 pounds of 9260 bar stock cut to length and stacked in a Lincoln log style tower*

As mentioned in section 3.0, it was decided that we would purchase 3D printed sand molds from Humtown Additive. In total, we had six molds with corresponding cores printed at their Leetonia, Ohio facility. Preparation of the chills prior to pouring ensured maximum efficiency and easy removal from the casting by means of a shop hammer and chisel. Every chill that was placed in a mold was thoroughly ground to a uniform thickness and sandblasted to remove materials that would contaminate the casting. Placing a quarter round piece in each of the four quadrants of the hammers faces allowed easier installation in the mold on either side of the parting line. Additionally rectangular chills were placed in their respective cutouts, which had been printed into either side of the hammer body of the mold. All chills were glued in place with Hill and Griffith Company Shurstik 306 composition, which is an alcohol based quick drying core glue. Each mold was then air blown and hand swept to remove any particulate and closed using five ½ - 20 UNF all thread rods three feet in length the matching nuts and 3.5 inch diameter washers.

5.3 Pouring The Hammer

With the furnace rebuilt, the molds prepared, the bar stock stacked, it was now time to get to the fun stuff. As discussed previously, Figures 10-13 depict our metal flow during casting of the hammer as it flows through the 3D printed sand molds. Figure 16 shows the molds being put into practice in the Materials Lab. Pouring in sets of two molds at a time, all six of the Humtown 3D printed sand molds were consumed by our team during KSU-AFS chapter meetings, after hours, and on weekends when the lab was not in regular classroom use. Figure 17 shows an assembled mold setup wherein the threaded rods hold two molds together for the liquid metal to flow into.

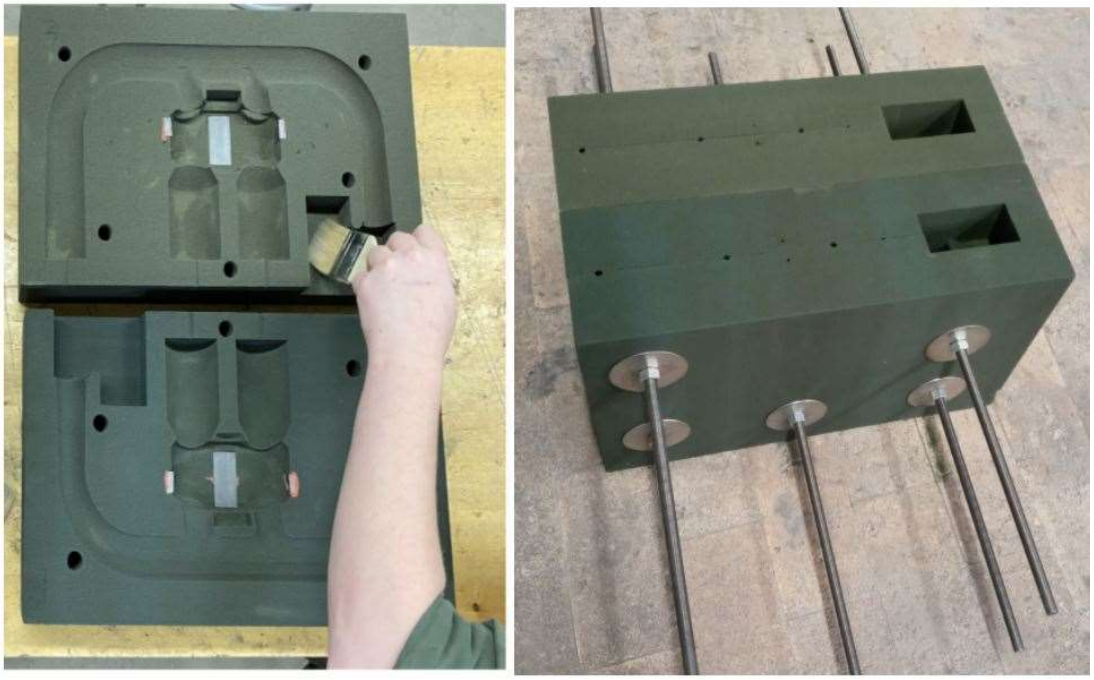


Figure 16: 3D printed sand molds being prepped for a steel pour
Sara Roman brush cleaning and a pair of closed molds

Figure 17: Steel pouring of final two sand molds
Silvers: Dan Yost (left) and Justin Warlop (right)

6.0 FINISHING

Left to cool overnight, each mold was opened to reveal the spoils of our labor, but now began the real hard work. The longest stage of the production process from start to finish were the hours sunk into grinding the burnt in oxides from the castings. The downside of having such unique geometry for a casting was the detail required to clean up the surface finish without compromising the defining features. All finishing work was completed by hand using three tools that excelled at three different applications.

Surface finish was a factor that was heavily experimented with due to the aesthetic and mechanical properties that each process would provide. The initial goal was an industrial shot peening at Pentair out of Ashland, Ohio thanks to the connection of a graduated AFS chapter alumni that had secured employment as a Process Engineer. This ended up being detrimental to the final product as shown in Figure 18. The aesthetic effect was exactly as hoped for, especially after fitting to a stained handle as shown in Figure 19; this was rejected as a competition piece due to the detrimental porosity on the underside.

Figure 18: *Under riser porosity revealed after the Pentair shot blast*

Figure 19: *Before shot peening on test handle*

6.1 Grinding & Welding

Face hardened with Manganese welding stock for impressive giant slaying potential. The seat of the handle is best described as two elliptical conic sections with the shorter placed on the bottom of the head so as to fit snugly on the shoulder of the handle. The top conic section is a more gradual taper intended to catch the draft created by the wedges driven in to splay the “eye” out, resulting in the tightest possible friction fit. Angle grinding removed the bulk of the exterior layer shown in Figure 20. This was by far the most dangerous part of the finishing process due to the proximity of the angle grinder’s blade to the operator’s fingers. The Faculty Advisor provided special oversight while students were using this tool to ensure proper technique and safety during the bulk removal of material. Only one team member was entrusted with this process to mitigate risk and allow time to get a feel for technique.

Figure 20: *Dan Yost cleaning casting surface with an angle grinder*

Chicago Pneumatics air tools were especially suited for the deep geometry that was too tight of an area to get other grinding tools in. The pneumatic sanders were fit with grinding stones for the inside diameters of the upper and lower curvatures, allowing precise removal without accidentally gouging out the work piece. Figure 21 shows one of the castings being cleaned up using this method with the 90° head which offered more controlled motions. The cutouts of the ribs were hogged out with a special order SB-3DT DBL CUT TIALN COATED Bur with a flat bottom; this was selected from McMaster-Carr specifically for this geometrical feature, and fitted to the straight necked air tool for downward force to be applied.

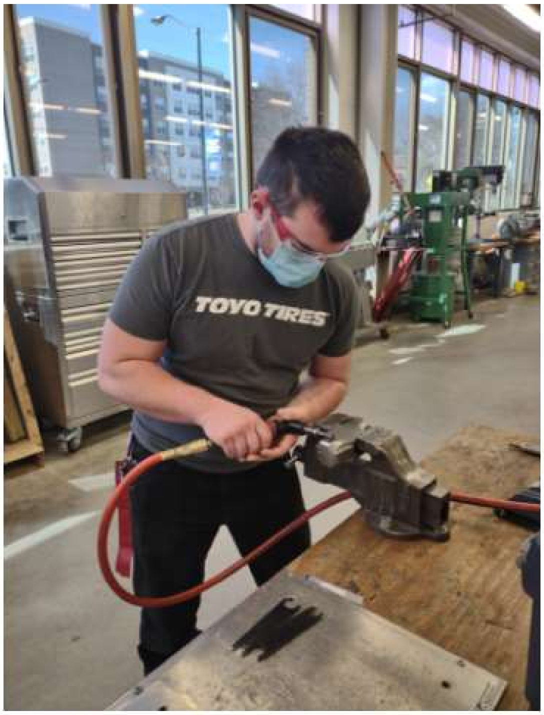


Figure 21: *Justin Warlop using a chicago Pneumatic tool with a double cut bur attachment*

The Kent State University Materials Lab purchased a Brodbeck 2''x72'' modular belt grinder which offered a variety of cutting surfaces that worked into many areas of the finishing process. The small diameter wheel specialized in the curvature between the handle hole and the bevelled faces of the casting, allowing easy removal of material as shown in Figure 22. The slack belt ended up as the most efficient way to apply the finishing crown to both faces of the finished hammer because of how well it wrapped around the edges. Deft rotation and even pressure resulted in a precise rounding of both faces which resulted in a better finished product.


Figure 22: *Nicholas LaRose testing out the new Brodbeck Grinder*

6.2 Handle Application

There were several attempts at crafting a handle that fit the design's needs that experimented with different shape factors, stain colors and surface sealer application. The final product presented in the submitted hammer had a curved recess cut to more comfortably fit the hand. In conjunction with the style of leather wrap and handle this meant the form factor was exponentially improved for the end user. The stain chosen was Verathane's premium gel stain named "Kona"that offered the rich color evident in the final product. The bonus of using a gel stain was better pore penetration which brought out the natural grain structure inherent to the hickory handle. Two layers of stain were applied to balance between the rich color and the expression of the wood fibers. Lastly thin layers of Master Kincote Lacquer were applied, then allowed to dry before being rubbed down with fine 000 steel wool to get a pleasing glossy finish.

6.3 Leather Wrap

The grip of any tool is paramount to the effectiveness of the implement. Too smooth and the user could lose their grip, too bulky and the item may be unable to be gripped at all. Knowing that our hammer would be put through additional testing by users of varying hand sizes, the decision was made to add a section of wrapped leather lacing and a braided wrist strap to maximize the grip and ensure safe use. We chose ¼ inch Kodiak oil tanned leather lace in a complimentary carmel color for this task. After using one of our sample handles to attempt various complicated braiding and weaving techniques derived from youtube tutorials, we decided on a simple self cinching single wrap with an integrated three strand flat braid.

A portion of the wooden handle was sanded down to match the depth of the lace, thus allowing the leather to create a seamless transition from wooden handle to the wrapped grip zone. To integrate the wrist strap, three strands of lacing were flat braided then lined up along the entire length of the posterior grip section. These strands were then coil wrapped using another length of the same lacing with the leading edge placed flat on the anterior of the grip zone. Once finished we were able to carefully pull that leading edge and trim the excess to create an extremely snug clean ending knot. This method took several iterations to get just right, but the end result is a comfortable grip that mitigated impact shock with an integral wrist strap.

Figure 23: *Handle wrap detail shot*

7.0 FINANCIAL ACCOUNTING

All projects have an inherent cost associated with them. Thankfully our team members have the privilege of also being members of the KSU-AFS student group. As such, per the organization's bylaws, we were able to procure funding without having to channel our inner Loki and steal what we needed. In the below table, Figure 24 you can see that we have accounted for all of the funds we spent in our quest for blessings from the allfather, or SFSA, we'll take either.

Items:	Purchased from:	Price:	Qty.	Total Spent:
Hammer Handles	McMaster-Carr	$43.89	-	$43.89
3D Sand Molds	Humtown Additive	$70.00	6	$420.00
Leather Goods	Tandy's Leather	$43.17	-	$43.17
Grindingstone Attachments	McMaster-Carr	$141.28	-	$141.28
			TOTAL SPENT:	$648.34

Figure 24: *Financial accounting for purchased materials*

8.0 EPILOGUE

In summation, we have been through it! This challenge has afforded us the opportunity to conceptualize a design, physically labor and troubleshoot our decisions and then step back to evaluate our process in technical format. Not many programs, let alone educational settings, offer such an involved process in one project to give such a well rounded experience before entering the "real world" and facing these hurdles with a paycheck on the line. To Steel Founders' Society of America, we say thank you for this opportunity. Next, we'd like to offer our unending gratitude to our Faculty Advisor, Trent True. Had he not been willing to open his lab and burn the late night and weekend oil with us, this project never could have happened. We'd also like to acknowledge those businesses that provided goods and time to assist in the completion of our casting; Humtown Additives for the molds, FOSECO for providing a new liner quickly, and Pentair for shot blasting services. We are extremely proud of the product that we present to you. Our hope is that it will withstand whatever additional testing that you put it through and that in the end we will be deemed worthy of wielding this hammer in the eyes of the Gods. **Skål!**

Mjölnir Team