SFSA Cast in Steel Competition
Thor's Hammer

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Special Acknowledgments

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AEROTEC ALLOYS

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<u>Team Members</u>

Cesar Rodriguez:

I am a Manufacturing Engineering Transfer student at Cal Poly Pomona. I am expected to graduate in Fall of 2021. This will be my second year participating in the SFSA Cast in Steel Competition. I am interested in Metalcasting, CNC machining, 3D design/printing, and Quality Control. I am aspiring to one day work in the aerospace industry, where I am able to apply my interest and knowledge to the best of my abilities.

Daniel Carranza:

I am a transfer student who is currently pursuing a degree in manufacturing engineering at Cal Poly Pomona with a graduation date set to Spring 2022. I am mostly interested in additive and subtractive manufacturing methods and also quality engineering. In addition, I would like to work in the aerospace or electric vehicle industry.

Nickolas A Raymundo:

I am a transfer student pursuing his Bachelor's Degree in Manufacturing Engineering at California Polytechnic University of Pomona. Currently I am in my senior year of the curriculum and expected to graduate in Spring 2021. I am highly intrigued by the growing technology that has been evolving the metal casting industry and the overall process of it. I took this opportunity to compete in SFSA's Casting in Steel Competition, even though this may be my first time participating. I am excited to deepen my knowledge and experience with the metal casting process.

Bryant Vieyra:

I am currently a 5th year manufacturing engineering student at Cal Poly Pomona with a graduation date set to Fall 2021. This will be my second year participating in SFSA. However, I did not complete the competition due to the current situation of Covid-19. I am interested in foundry work and quality control work. Furthermore, I am interested in working in the aerospace industry and automotive industry.

Amber Reyna:

I am a 2nd year Manufacturing Engineering student at Cal Poly Pomona with an expected graduation date of Spring 2023. I am interested in 3D printing and metal casting.

Abstract

For the 2021 Cast in Steel, our team was given the goal of designing and casting Thor's hammer from Norse mythology. Thor is the Norse god of thunder and carries the hammer named Mjölnir. Mjölnir is generally depicted as a large war hammer with Thor's symbol that was used to crush Thor's enemies in battle.[1]

The design of the hammer head was made in Autodesk Fusion360 and Solidworks with the head measuring 5.35 inches and an estimated weight of 3.45 lbs given that the parameters for the hammer was 6lbs and 20 inches in length, including the handle. After some careful consideration and researching a variety of different steels we found that 4140 Alloy Steel would best suit our needs since it has high strength, hardenability, and good toughness.

The casting method we decided to use for this project was investment casting. Our design had many intricate features that we wanted to come out in the casting and because of this we decided that investment casting would be the best.

Our pattern was created by the use of an extrusion 3D printer with the filament being Moldlay, a wax like filament. With the help of Fenico, we were then able to attach our created pattern to the gating system, which was also made of wax. In total we created 4 patterns and each tree assembly held four hammers.

From here the gating system and the hammer was then coated in the ceramic slurry and ceramic powder. Once dried, the shell created was heated, and the wax and filament were melted and blown out from the shell. The melted 4140 steel was then poured into the shell creating our four hammer heads. After the hammer heads were removed from the gating system they were then heat treated for maximum toughness and an increase in hardness. After the heat treatment the hammer heads were then polished and the handles, which are made of hickory wood, were sanded, hand carved, and stained.

Figure 1: Drawing of archeological Mjöllnir found in Öland, Sweden[2]

Introduction

In this project, a hammer based on the one owned by Norse god Thor was designed and manufactured with specifications given by the Steel Founders' Society of America for their Cast in Steel competition. The Cast in Steel competition allows for college students to apply their knowledge of computer modeling, material selection, additive manufacturing and casting concepts and techniques to make a complete hammer.

There were two parameters that SFSA provided about the hammer design that the teams needed to follow. Firstly, the weight of the entire hammer, with handle included, could not exceed a weight of 6lbs. Secondly, the length of the hammer could not exceed more than 20 inches. In addition to these parameters, the hammer also had to resemble that of Thor the god of thunder.

The basic features of a hammer can be seen in figure 2 below.

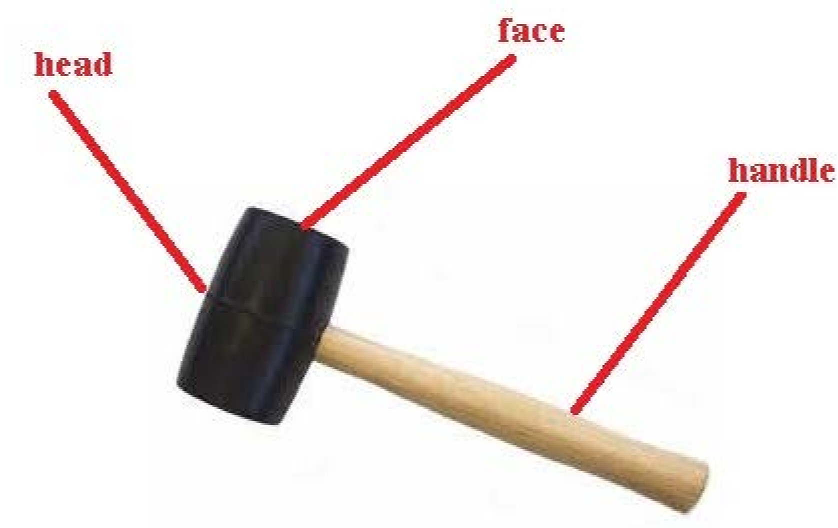

Figure 2: Anatomy of hammer

Historical Background

Mjölnir is the hammer carried by Thor, the Norse god of thunder. For the most part there are two iterations of Thor and his hammer that can be seen. One which follows a historical context and the other which is based in popular culture, such as the Thor and Mjölnir seen in Marvel Comics and movies. A historical replica of Mjölnir can be seen figure 3 below. As stated before, the popularity of Thor and Mjölnir has risen ever since the character and weapon was introduced by Marvel Comics.

Figure 3: Historical Replica

In the original tail of the hammer's origin it was actually forged by dwarves and not at all casted. The hammer was given to Thor as a gift because his brother Loki decided to cut the hair of Thor's wife. Furious, Thor threatened Loki's life and to get out of this predicament Loki decided to pitt two families of dwarves against each other to see who can create the better gifts for the gods. From these gifts, one of them was Mjölnir which was given to Thor. According to legend, Mjölnir will never shatter, never miss its mark, and always return to Thor when called upon.[3]

Figure 4: Thor Hammer movie (modern)

In figure 4 can be seen a modern representation of Mjölnir. As you can see, the designs on the modern version drastically differ from the historical version. The head of the hammer is more box like and bulky when compared to the historically accurate version. The head of the hammer is also larger than the historically accurate version.

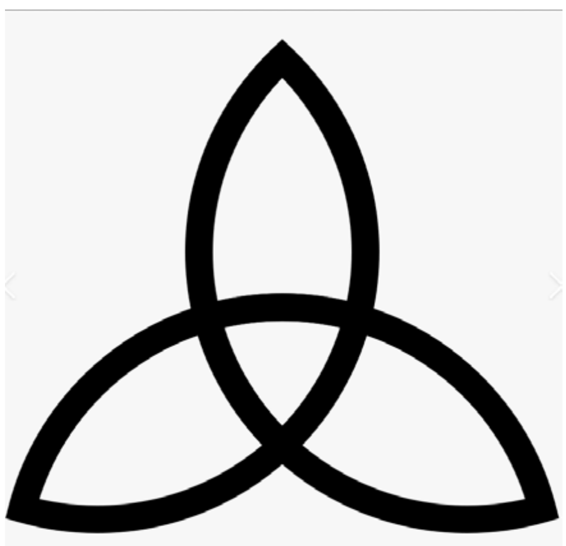

Figure 5: Triquetra, a symbol often referenced and connected to the Valknut and Horn Triskelion.[4]

The symbol seen in figure 5 is seen many times in Viking culture and is often associated with the Valknut and viking paganism. Despite this, this symbol is still seen in popular culture and is often associated with Thor.[5]

Hammer Design

After brainstorming for a couple days, we decided to base our design off the historical and modern versions of Thor’s hammer while adding our twist to it. Continuing on with our research, we developed designs that were inspired by Nordic knots, ribbons, and other ornaments.We made it a priority to design the hammer to include ideas from each team member. The hammer has a length of 5.4 inches and a width of 2.25 inches. The handle has a length of 8.5 inches starting from the bottom of the hammer. In total, the hammer has a length of 10.5 inches. After the general shape of the hammer head was complete, each team member added additional designs to their own hammers. From there the design features that each team member created were then transferred to the final CAD of the team hammer. The estimated weight of the hammer was 3.45lbs and once casted the four hammers ended up weighing around 3.3lbs to 3.5lbs.

CAD Model of the Hammer Head

For the CAD portion of this project; we used two software programs, Fusion 360 and Solidworks. Fusion 360 allowed us to CAD all of our designed Mjölnirs and combine what we all wanted to include in our final design (Figure 6). We chose to do more intricate features and made the hammer with very complex designs. We wanted to challenge the limits of investment cast with this hammer design.

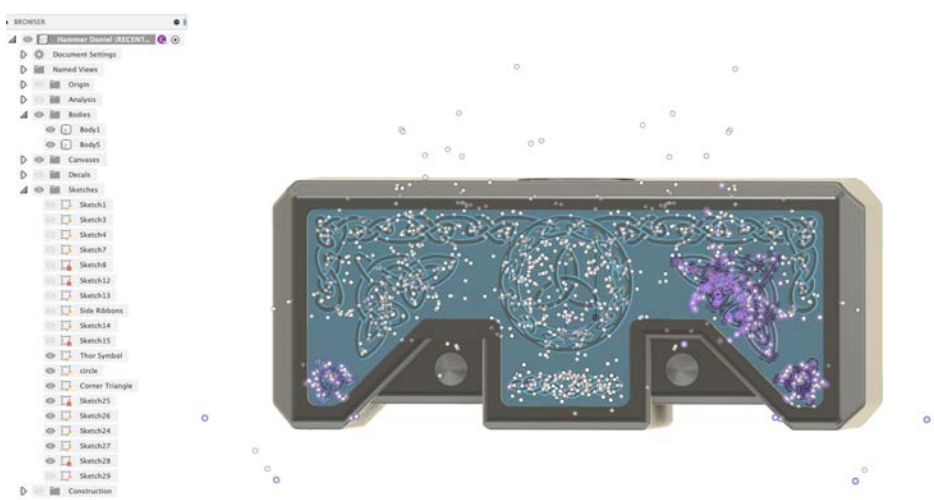

Figure 6: Here is a picture of the hammer with all the sketches that were created that were used to make the design of the ribbons and knots.

The team did overcome challenges while doing the CAD for this hammer. Our designs were so elaborate, that Fusion 360 crashed 7 times, on 3 different computers. When the crashes kept occuring, we converted the Fusion 360 file into solidworks and continued our design process. In Figure 7, one can see the final design of the hammer.

Figure 7: These two pictures are our final CAD model of the hammer.

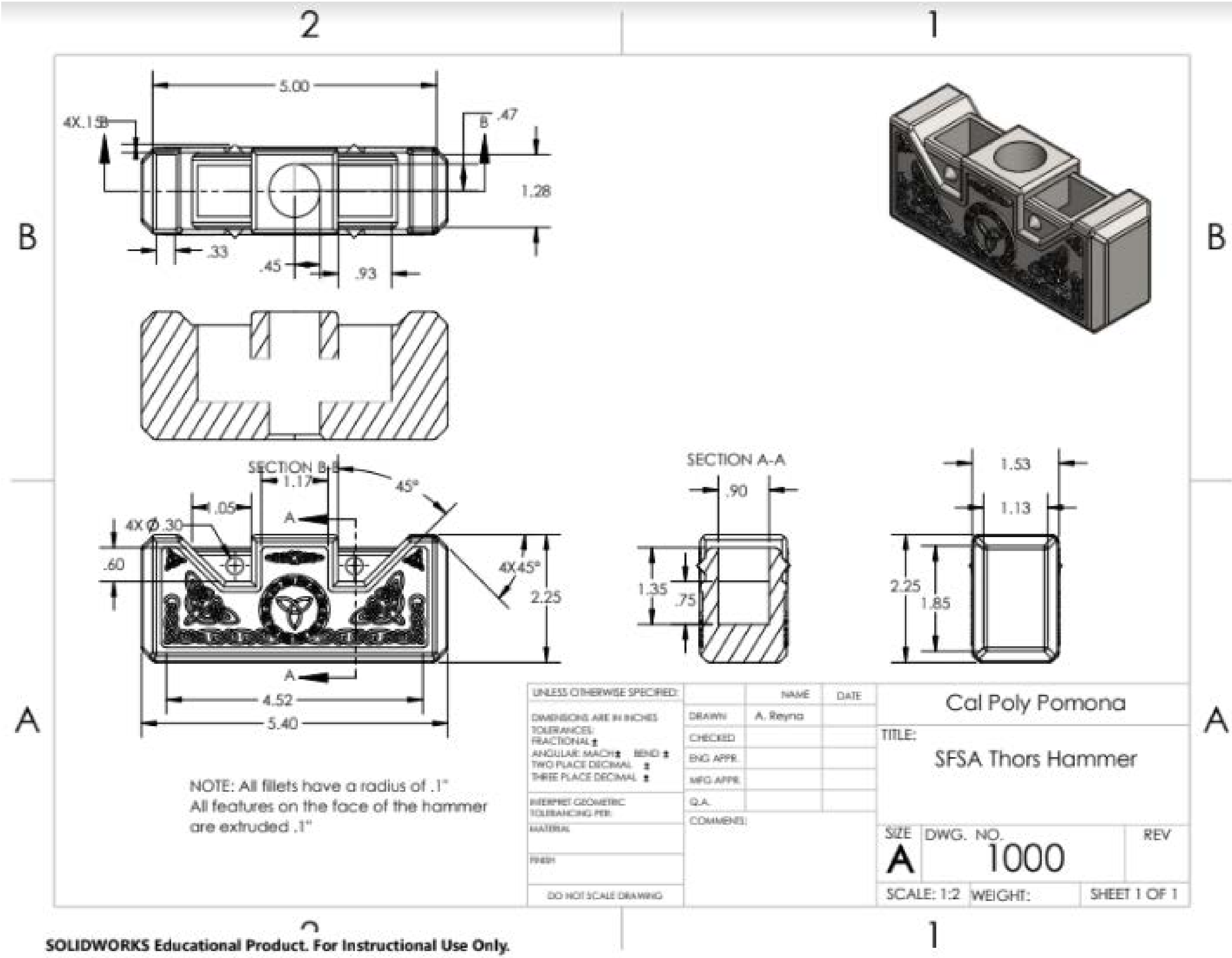

Figure 8: Drawing of our hammer

Once we finished the hammer design, we came up with our gating system CAD models. This helped tremendously due to the fact that we had to simulate each design to be able to optimize our casting results. Our team's initial gating system did not account for the amount of hammers we wanted to cast, nor the capabilities of our sponsored foundry, Fenico Precision Casting. But with some communication with Sonny, the President of Fenico, we were able to gather some insight and direction on how to design our new gating system, which can be seen in Figure 9.

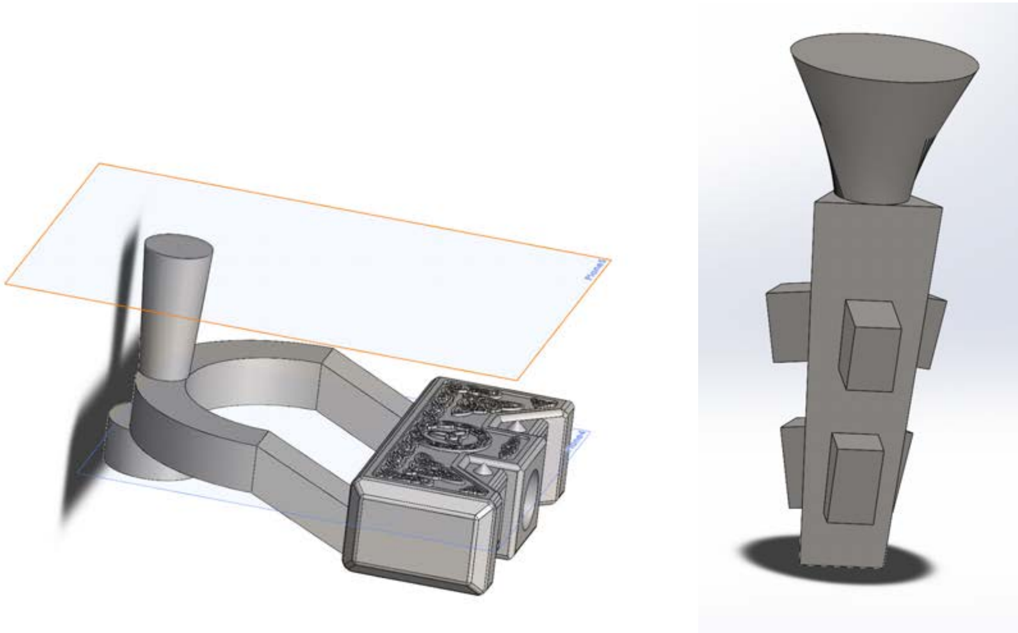

Figure 9: The picture on the left is our very first gating system that we model up to be able to run simulations. The picture on the right was our redesigned and optimized gating system and the system that we intended to use.

<u>3D Printing</u>

3D printing is an additive manufacturing process where the printer is given a G code that is followed by an execution process where filament is heated through an extruder. Then as filament is being melted by the extruder, it is stacked layer by layer to complete the desired shape.

Due to the fact that we were going to do an investment casting process for the hammer, we had to consider that the hammer needed to be made from wax to be. We had to choose between making a wax mold of the hammer or to 3D print the hammer. We figured that the mold would be too expensive, the tooling would be difficult and too time consuming to do. The very complex designs would be difficult for a mold that would have to include radii and some draft to be able to make and remove a wax pattern out of any mold. Creating a 3D printed mold would be the best option and fastest results for this project.

We began by learning how to use the program FlashForge to be able first create the 3D printing file. We learned how to split the model in half to be able to print the complex designed on the face of the hammer, as well as learning how to use adjust the parameters on the file type. Then we learned about the support features that are needed to be able to hold up the print filament while printing. Once becoming more adequate with the program. We were ready to be able to do our first sample run.

We started by just printing on a section of the hammer to see if the face of the hammer would come out. In Figure 10, it shows how the part was sliced on Flashforge and the first test to see how well the first test came out to be.

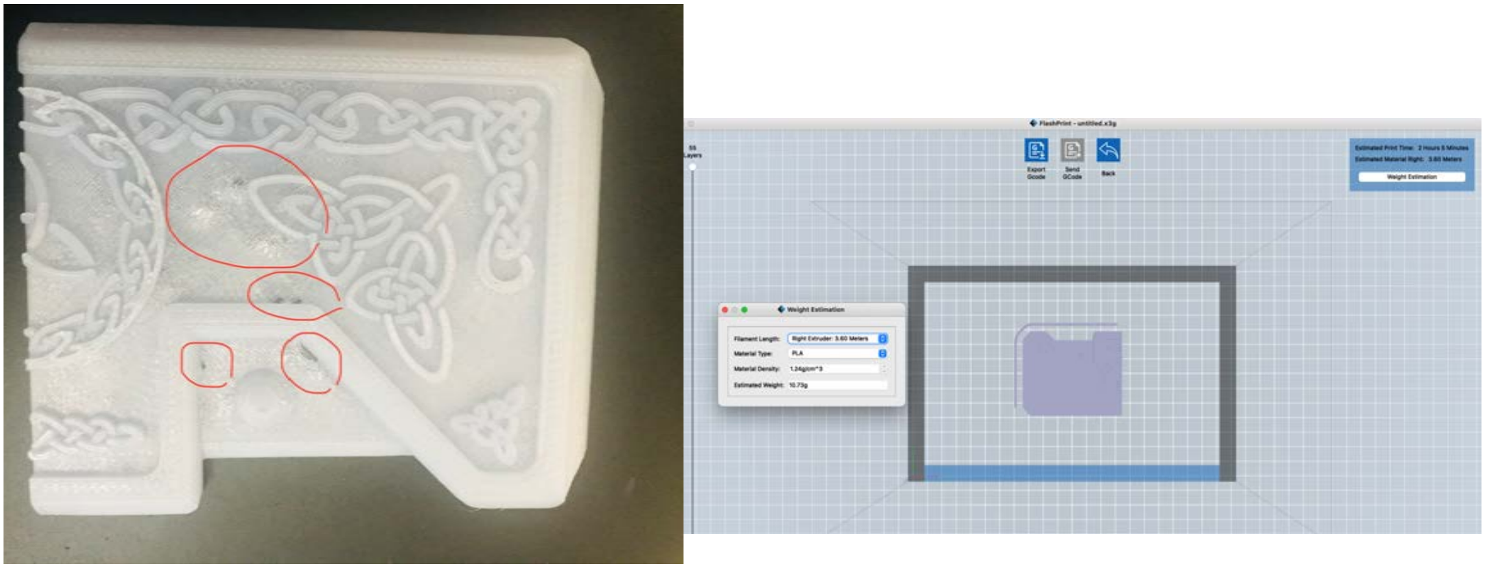

Figure 10: The picture to the right is the sliced part on Flashforge getting it ready to create the 3D printing file. The left picture is the results of the first print.

The lesson learned from the first print was that we needed to adjust the parameters of the printing program. It was very difficult to get the parameters right because we were using a fairly new filament called Moldlay for the first time. Moldlay is a filament that has wax-like properties that is meant for investment casting.[6] It is meant to melt out at the same temperatures as wax, which would be perfect for the investment casting process.[7] Since we used this new type of filament, it was challenging to get one to print correctly. We lost a lot of time attempting to print these hammers. Due to the pandemic, we were very limited to resources. We lost several weeks trying to get the hammer printed trying to get the right settings and the 3D printer we used kept crashing on the prints. It was difficult to watch the prints since they took over 14 hours to print one hammer. Every time something went wrong with the printer, that was partially a day lost. Figure 11 shows the quality of the hammers that were coming out. We learned that the most optimal temperature to extrude at was 220ºC and keep the bed of the 3D print at 40ºC with 5% infill so that when the burn out process happens, its not taking long to melt out.

Figure 11: In this picture, one can see that this print has holes on the top surface. This would not be usable for an investment process because the slurry would seep in.

With the assistance from Dr. Dika Handayani and Andy Gustilo, we were able to get a few high quality prints. It took our team a total of 4 weeks to be able to get four and a half hammer prints. Due to losing so much time trying to figure out the parameter, we had to outsource to a fellow classmate of ours, Matthew Cefalo. He was able to print out the remaining and a half hammer prints. Without the help of Dr. Handayani, Andy, and Matthew, our team would have not been able to cast these hammer. Figure 12 shows the print done on Prusa with Cura slicing software and Figure 13 is the print done on FlashForge with FlashPrint software.

Figure 12: Print done by Matthew on Prusa with Cura slicing software

Figure 13: The top two prints are the ones print done on FlashForge with FlashPrint software.

Casting Approach and Optimization

Given the competition requirement of using the manufacturing method of metal casting versus other methods within manufacturing, our team ran into a couple of challenges along the way. Normally hammers are manufactured by a process known as drop forging. A hammer is categorized as a tool, and tools are designed for being tough and having long lasting durability. The difference between drop forging and metal casting is that each process treats the microstructure of the metal being used differently. The level of complexity in terms of shape can be greater when casted, forging is limited to size and alloy selection. Also the overall general cost tends to be cheaper for casted parts and any post-casting parts are closer to required specifications.

Our team had to make a key decision on whether to use sand casting or investment cast so that we can continue with our project. If we went with sand casting the necessary steps our team would have to go through are first choosing and designing a type of pattern, which can either be a split pattern, cope and drag pattern, matchplate, etc. The next step would be creating the entire mold which can be broken down by packing sand in the flask while surrounding the pattern. Since the pattern does not include the sprue and pouring basin, our team or a worker would have to create one by piecing the sand with a sprue former. Once the mold assembly of the cope and drag together, molten metal can then be poured into our mold through the pouring basin. The last step would be having to retrieve the casting within the mold.

Investment casting on the other hand starts with the same step as sand casting but instead the pattern will most likely be made out of a material that can be melted out. After the patterns are made each pattern is attached to the gating system which is also known as a tree in investment casting. The next main step is to prepare the shell mold by dipping the pattern into a slurry, and once the slurry has dried the mold will go through the dewaxing process, in which the shell mold goes through an autoclave where the mold is heated up to melt the wax pattern. And once the mold reaches a specific temperature then the process can continue to the next step of pouring the molten metal. Last step is breaking off the shell and retrieving the parts from the mold by the use of cutting machinery.

The difference between sand casting and investment casting is that investment casting is able to cast very complex shapes with the thinnest walls that any other casting process can produce. Also the dimensional tolerance can be tighter in investment casting rather than sand casting, and can produce the best surface finish out of any casting process as well.

After weighing out the pros and cons about each casting process, our team decided on using investment casting as our method to create Thors' hammer, due to mere fact that our team wanted a challenge because we have had no hands on experience with investment casting. A couple of other reasons why our team chose investment casting was because of the producible surface finish, ability to cast complex shapes, and the ability to negate any use of cores within the mold.

Once our group finalized our final hammer design, we were able to switch our focus on optimizing the gating system to minimize shrinkage and material beings used, also to maximize the amount of parts that we will be able to fit on the tree. Before jumping into designing the gating system we settled as a team on how many hammers we would want to produce, resulting in having to produce six hammers. And since we didn't have any experience with creating gating systems for investment casting, our team brainstormed and researched different gating designs. One of the first obstacles we faced during our gating optimization was that through the use of SolicCast, we found a pattern of shrinkages around the bottom part of the hammer and where the gates were. The shrinkage within one of the initial gating designs is shown in Figure 14.

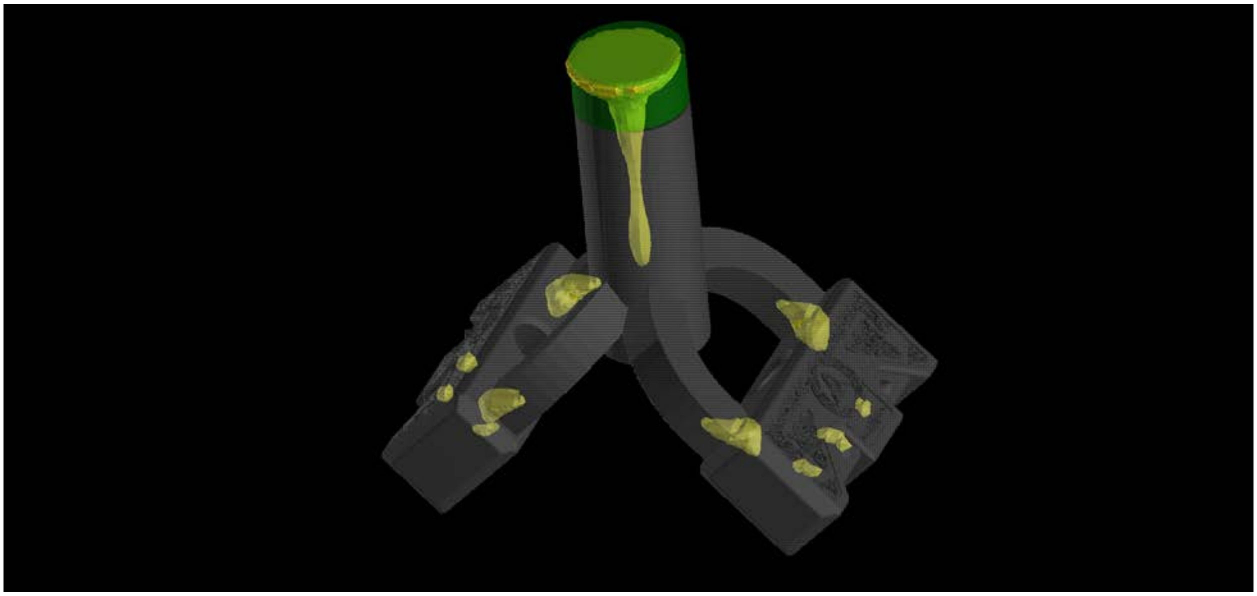

Figure 14: Initial gating design to produce two hammers

After numerous attempts, our team reached out to Sonny from Fenico Precision Castings, whom we partnered up with, and asked for some help on reducing the shrinkage that was appearing in the hammer during simulation. He recommended going with a tapered triangle “tree”, because he mentioned that design is one of the standard types of trees that are used in investment casting, also it was available at their foundry. Our team kept the same gating entrance, but changed it from 0.8”x0.8” square gating to the top gate cross-sectional-area of 1.5”x1.0” and the bottom gate cross-sectional-area of 1.75”x1.0”. The newer revised gating system was able to accommodate three hammers as well, and the shrinkage was only shown in the tree section of the casting. This can be seen in Figure 15.

Our team unfortunately faced many challenging obstacles with our patterns that were mentioned in the 3D printing section. Our team had to scrap many of our 3D printed patterns because of the various defects that appeared on them, resulting in a big setback for our project timeline. Once we were able to retrieve our 3D printed pattern, which was made with moldlay, that contained miniscule amounts of defects, we ran into another problem because we were only able to produce four hammers with the amount of filament that was purchased. With the amount of the hammer patterns produced we had to do a last minute finalized change to the gating system. Ana, one of the foundry operators, advised us to go with a basic gating system and to also include a wax blow-out feature, which is used specifically at Fenico. A blow-out pathway is a riser looking feature that is used to “blow-out” any excess wax filament in the mold after going through an autoclave to ensure the mold is clear of any debri. The “blow-out” feature will help with pouring the molten ST4140 into our shell mold easily, and also acts as a riser for the mold. In our final revised gating system we went with a more traditional style of gating design that included the casted part being horizontal, a runner, and wax filament blowouts that acted like risers. The new gating system tapered from a cross-sectional-area of 2”x1.5” to 1.8”x1.0” on both sides, and a large runner with a volume of 2”x1"x16”. With this new gating system our team was able to simulate it through SolidCast, and find out this design was more ideal than the triangle tree gating system. In Figure 16, you can see this design had no signs of shrinkage within the casted part or gating system and only appeared in the pouring basin, and it showed that our hot spot was located where the pour basin met with the runner.

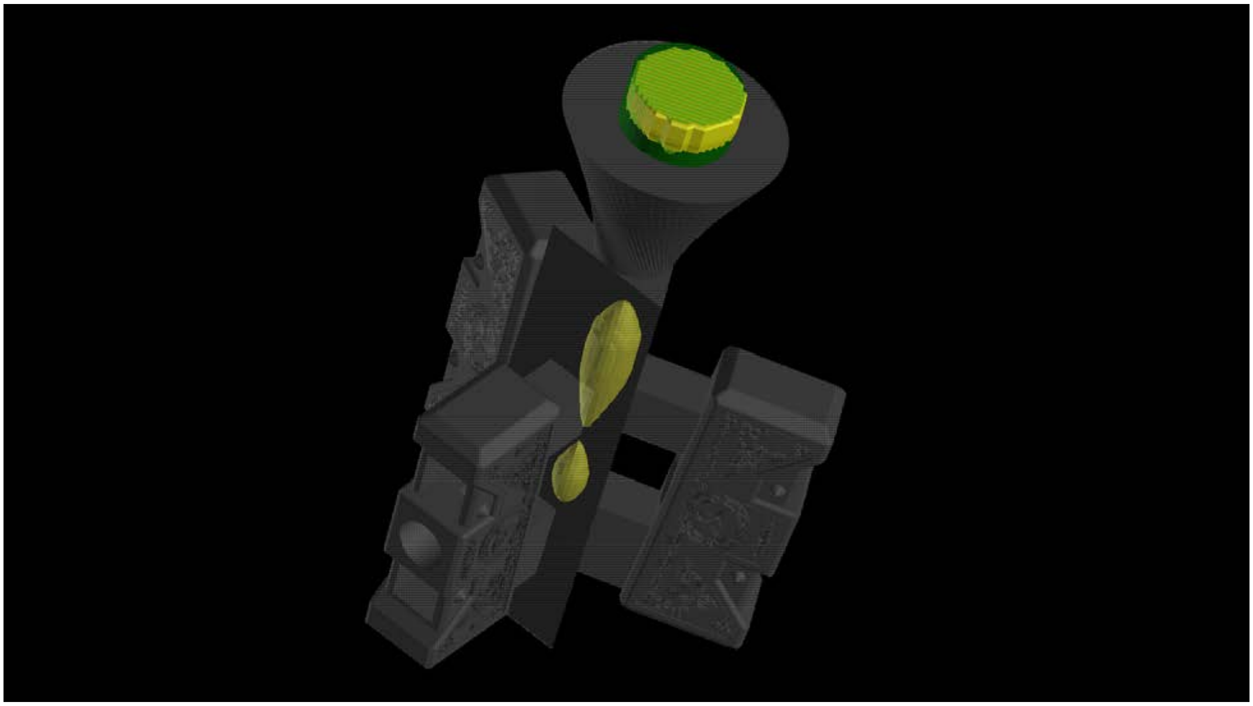

Figure 15: Solidcast Simulation of the triangle tree gating system to produce three hammers with shrinkage only in the tree without wax filament blowouts, to have any excess wax moldlay exit the shell mold after going through an autoclave.

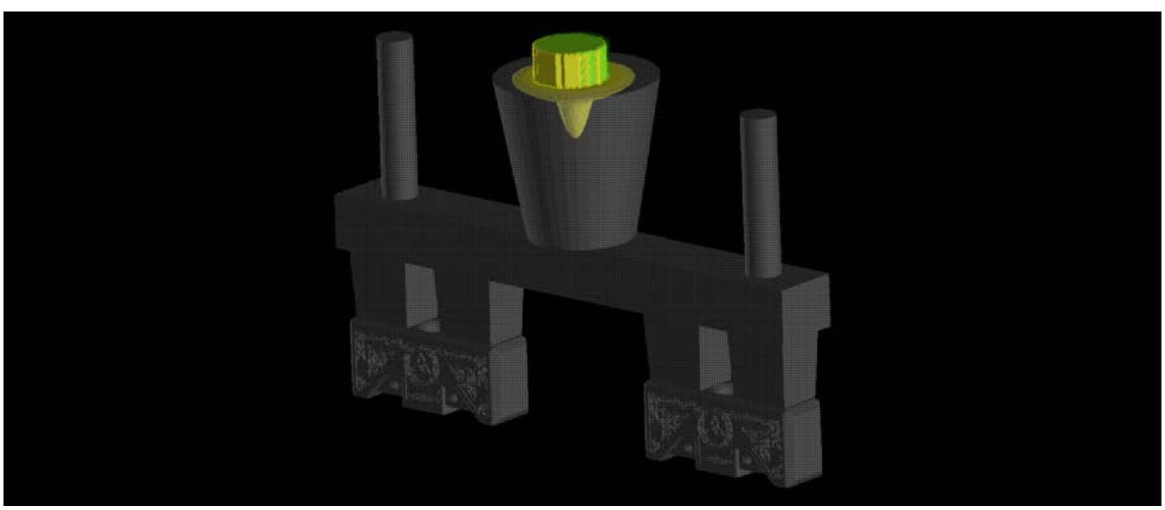

Figure 16: Solidcast simulation of revised gating system that shows no sign of any shrinkage in the hammer with included blow-outs.

After revising the gating system our team went forward with our new timeline of the project, and in one day we made the full wax pattern that included the entire revised gating system. The process of completing the full wax pattern can be pictured in Figure 17a and 17b. Once our team and the operators who helped us complete the full wax pattern, we went to the next with creating the ceramic shell mold, which was around a week process. The operators who helped us did six coats of slurry and ceramic dust, with wait time in between for each coat to dry, which can be seen in Figure 18. After we got confirmation that the shell mold making process was complete from Sonny, several of our team members went to the casting facility to see the two next steps in the investment casting process. Before the Fenico operators were able to pour the molten ST4140 in the mold, the shell mold had to go through an autoclave process so that wax pattern that lived inside the shell mold was removed. After the wax pattern was removed through an autoslave, the shell mold had to be heated up 1925°F to help the molten metal stay in liquid form longer and not to shock the mold, which can be seen in Figure 18. This helps with ensuring any complex geometries within the mold is filled fully without any early solidification of the metal. In Figure 19, you can see the after picture of the molten ST4140 being poured into the shell mold, and in Figure 20, you can see the one of four hammers of the final casting process.

Figure 17(a): Adding the gates and runner to the hammer pattern.

Figure17(b): Finished gating system, Sonny Tran President of Fenico on right

Figure 18: First layer of the ceramic shell mold of our casting.

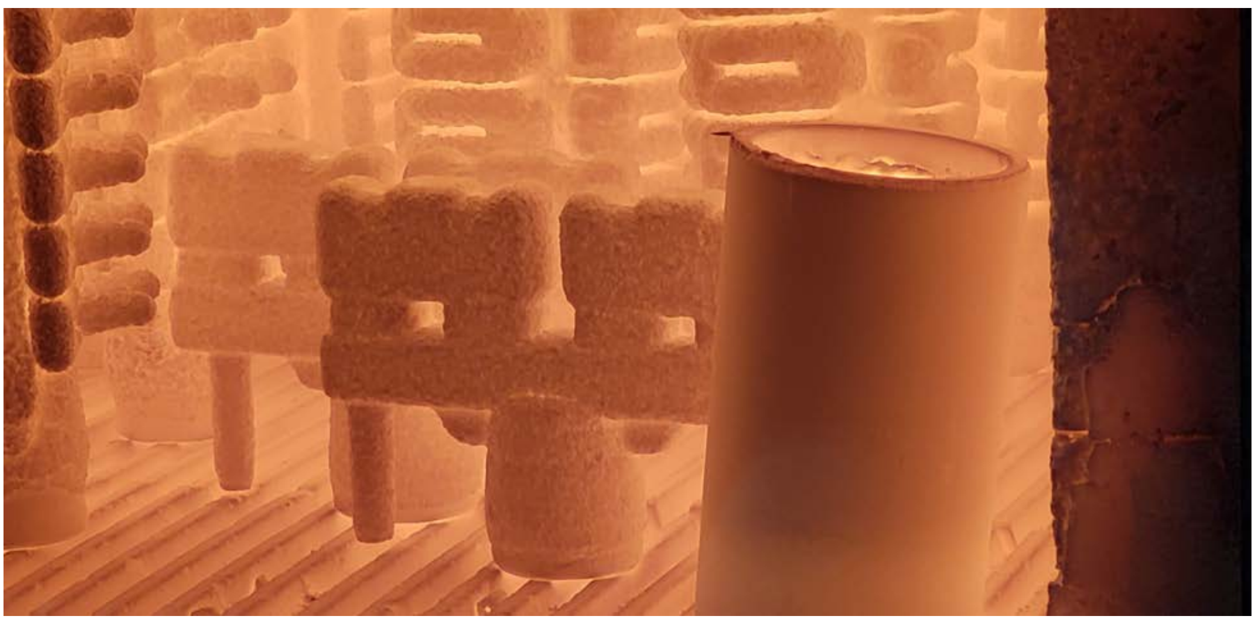

Figure 19: Preheating the mold to 1925°F before pouring

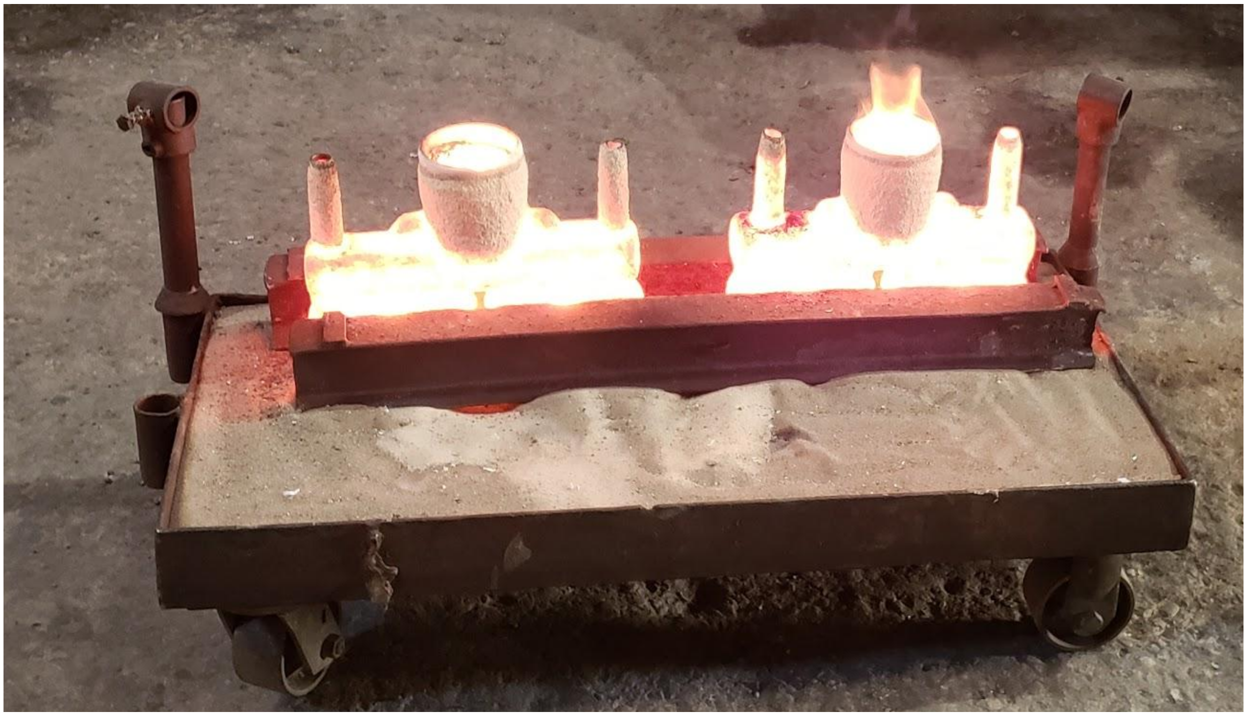

Figure 20: After the two pours of the hammer.

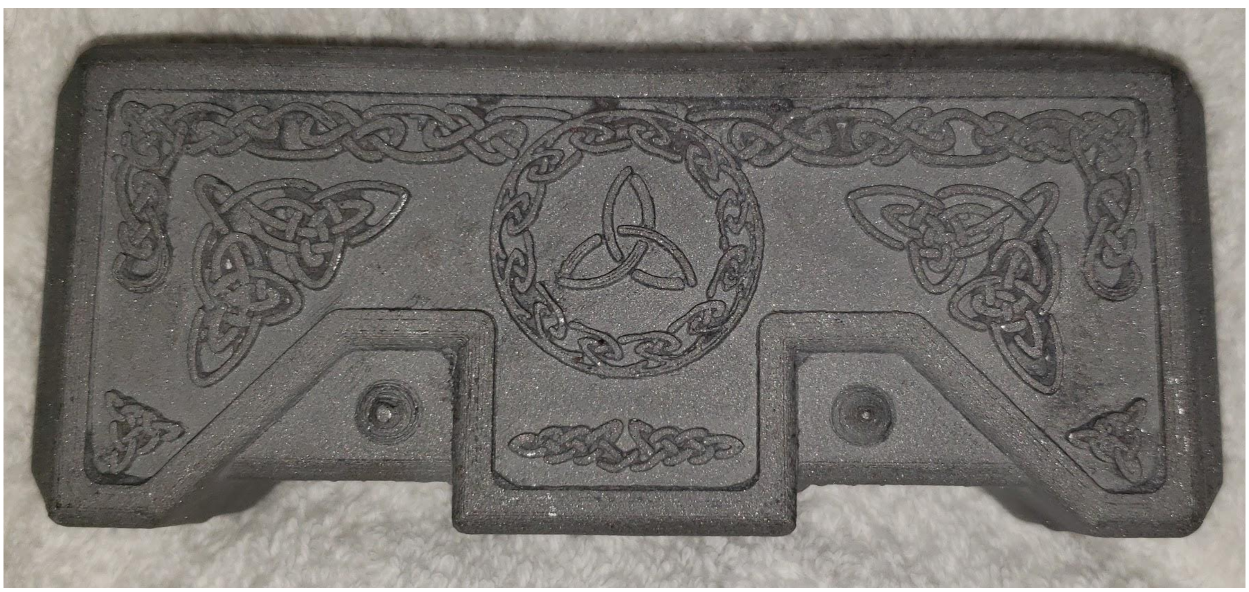

Figure 21: Final cast of one of four of the hammers with the gates removed.

Material Selection

Our team was looking for material that would withstand the tests that the SFSA performance part of the competition. First and foremost we knew the material needed to be made from steel since the name of the competition is Cast in Steel. From here we began researching different alloy steels and high carbon steels. Our research began with figuring out what kind of steels traditional hammers are made of. Hammers are usually made of medium carbon steels but the most common include 4340, 4140, and 1045-1060 steels.[8] From here we began to research these different steels and settled on 4140, but we wanted to compare what the differences were between 4140 and 4340.

These two alloys are very similar in composition but 4340 has a higher nickel content. The tempered and base material for 4340 also has better mechanical properties when compared to 4140 but the difference is not too substantial for our application. The cost of 4340 is higher than that of 4140 due to the higher nickel content in 4340. Since the mechanical differences were not too far apart and the main factor was price, our team decided that 4140 would best suit our hammer.[9]

Figure 22: Left is tempered 4140 vs 4340 and the right is just base 4140 vs 4340 steel. 4140 is the top bar and 4030 is the bottom

4140 Steel is made from carbon, silicon, manganese, sulfur, chromium, and molybdenum. It is considered a medium carbon and low alloy steel. Its carbon content and chromium allow the steel to be very hard having a HRB of around 92.[10] It is important to have such hardness in the material in order to maintain its structural stability and its wear resistance. The amount of chromium found in the steel also gives it a decent amount of corrosion resistance. This corrosion resistance will be helpful for when the hammer is shipped as the hammer will face different conditions that could change its mechanical properties while in transit. The other materials found in 4140 also help with the hardenability and grain structure of the 4140 steel. Overall this steel should serve our purpose well.

AISI SAE 4140 Chemical Composition

The table below lists AISI 4140 chemical composition.

	AISI SAE 4140 Chemical Composition (%)							
Steel (UNS)	C	Si	Mn	P (≤)	S (≤)	Cr	Mo	Ni
4140 (G41400)	0.38-0.43	0.15-0.35	0.75-1.00	0.035	0.040	0.80-1.10	0.15-0.25	–

Figure 22: Chemical composition of the 4140 Alloy Steel[11]

As you can see in figure 22, the mechanical properties of 4140 are desirable, specifically the hardness values that are displayed. The hammer will also be heat treated to increase the toughness and also gain a desirable hardness.

Properties	Metric	Imperial
Tensile strength	655 MPa	95000 psi
Yield strength	415 MPa	60200 psi
Bulk modulus (typical for steel)	140 GPa	20300 ksi
Shear modulus (typical for steel)	80 GPa	11600 ksi
Elastic modulus	190-210 GPa	27557-30458 ksi
Poisson's ratio	0.27-0.30	0.27-0.30
Elongation at break (in 50 mm)	25.70%	25.70%
Hardness, Brinell	197	197
Hardness, Knoop (converted from Brinell hardness)	219	219
Hardness, Rockwell B (converted from Brinell hardness)	92	92
Hardness, Rockwell C (converted from Brinell hardness. Value below normal HRC range, for comparison purposes only)	13	13
Hardness, Vickers (converted from Brinell hardness)	207	207
Machinability (based on AISI 1212 as 100 machinability)	65	65

Figure 23: List of various mechanical properties for 4140 Alloy Steel[11]

Heat Treating Process

The heat treatment of metals is a process that changes the mechanical properties of the material through various heating and cooling cycles. In general there are four different properties that change when a metal is heat treated: strength, toughness, ductility, and hardness.[12] When a hammer is forged, it is heated up while still solid and is hit with blunt force in order to change the microstructure and to get the desired shape. In general, forging would be the better option in terms of creating a hammer since it would achieve better mechanical properties such as finer grain size and overall better tensile strength and fatigue life. Of course this applies to just when the part is complete, meaning forging is better than casting if the hammer is only casted and not heat treated after. In order to achieve the best properties for the casted hammer we needed to make sure the heat treating process for 4140 steel was followed perfectly.[11]

AISI 4140 Steel Mechanical Properties

Material 4140 mechanical properties are given in the table below.

Steel	Tensile strength (Mpa)	Yield strength (Mpa)	Elongation in 50 mm, %	Reduction in area, %	Hardness (HB)	Sample diameter	Conditions
AISI 4140	1020	655	17.7	46.8	302	25.4mm (1 inch)	Normalized at 870 °C
	655	414	25.7	56.9	197		Annealed at 815 °C
	1075	986	15.5	56.9	311		Water quenched from 845 °C & tempered at 540 °C

Figure 24: List of the mechanical properties and values present in 4140 Alloy Steel[11]

With the heat treating of the hammer we wanted to achieve certain mechanical properties. The most important mechanical property we wanted through heat treating was the most amount of toughness we could achieve since we did not want our hammer to fracture. We also wanted to achieve a good amount of hardness so that the surface of the material would not be scratched during the testing. In figure 25 various temperatures and hardness values for tempering can be seen. Since we know that when hardness increases, toughness decreases we wanted the hardness of the hammer to be somewhere near the mid-lower end of the hardness values given below.

Material 4140 Steel Heat Treatment

The following table shows AISI 4140 steel heat treatment, rockwell hardness.

Material 4140 Heat Treat	Temperature (°C)	4140 steel hardness	Cooling/Agent
Normalizing	870	302 HB	Air
Annealing	790-845	197 HB	Furnace cooling
Quenching	830-845		Oil
Tempering (2 hour)	205	58 HRC	Oil hardening
	260	54 HRC	
	315	50 HRC	
	370	47 HRC	
	425	45 HRC	
	480	40 HRC	
	540	35 HRC	
	595	33 HRC	
	650	28 HRC	

Figure 25: List of heat treatment temperatures and hardness values for tempering 4140 Alloy Steel[11]

<u>Handle Ornamentation</u>

To create the handle we had to find the perfect material, to select the material of the handle we had to research different types of woods. The type of woods that we looked for were ones that were able to withstand high impact. From that we discovered hickory wood, which can withstand a hardness strength around 2000 lbs.[13] After conducting the research to see which wood would work best we obtained hickory handles.Then using a dremel we shaped the handles to ensure that they would properly fit within the hammer head. To add a personal touch we engraved our initials in Nordic symbols.[2] Nordic symbols have been known to be used by vikings.[2] Next we stained the wood with an all in one water stain and poly from Behr, the color chosen was American Chestnut Gloss. Once that process was complete we had to figure how to secure the handle to the hammer head. A wedging technique was used, to do this we used a metal wedge. All of these steps allowed us to create the most agile and sturdy handle possible.

Figure 26: Here is our handle. The symbols represent each of the team members initials in Nordic symbols. From top to bottom: CR, DC, NR, BV ,AR

Hammer Fabrication

Once the casting of the hammer head was completed, we then needed to remove our hammer heads from the gating system. We then began prepping the hammer. The first step was to remove all excess material. The tools and equipment we used was a dremel tool. The second step was to heat treat our hammer at Bodycote to increase the surface hardness, temperature resistance, ductility and toughness. Furthermore, we were fortunate enough to send our hammer head to Aerotec Alloys to be sand blasted and polishing that provided a mirror like surface finish. After, applying the finishing touches we then were ready to install our handle. The final total weight and length was 3 lbs, 8oz and 10.5 inches long.

Figure 27: Our teams finished hammer

Video Production

The videos were both created by the use of iMovie and were based on video clips taken throughout the entire process of this project. Some of the group members were not able to meet in person due to COVID-19 restrictions and the difference in distance from each other. Despite this we were still able to get everyone to participate in the first test video. It was very important that everyone was a part of that video since the hammer was an accumulation of all our work.

Conclusions

The Cast in Steel competition was a great opportunity for our team to really challenge ourselves, test our engineering abilities, learn to deal with setbacks and how to overcome them, and lastly working with industry and learning about the facilities. This competition really helped us to see how to engineer a product from start to finish. Starting from the simple idea of a hammer with parameters, to coming up with ideas and being able to collaborate amongst a team while making every member's idea validated. This hammer really has each member's unique touch to it. Then once we got the final CAD model done, we focused on our gating system to see what was our most optimal with no shrinkage. It was the first time any of our team members worked on doing an investment casting. While learning what was the best way to do our gating system, we checked each gating design by running a simulation on it. Once we had our gating system with no shrinkage, we started our 3D prints. This was our bottleneck of our project. Having spent 5 weeks trying to get a high quality 3D print with no defects was very difficult. We considered redesigning but believed in ourselves and did not give up on our ideas and overcome those obstacles. As the deadline came closer, we had to settle for only making 4 hammers. The gating system we originally made and simulated wasn't going to be used. Fortunately, the advice of Ana who had worked at Fenico for over 30 years suggested going with a different gating system that ended up working phenomenally in our favor. Once we got back the hammers, we were able to work Julio from Bodycote to be able to heat treat our hammer to increase toughness for this hammer. It was unfortunate that the facility had a power outage, which set us back a few days. Once we were able to get hammers back, we went to Aerotec Alloys to get them sandblasted and polished.

Our team was very excited with how our final product came out to be. If we were to do this project all over again, it would definitely be finishing the 3D print before the new year or having a team member that has a 3D printer. Despite all the setbacks our team encountered, we are happy to have had the opportunity to participate in such a great experience.

Special Thanks

On behalf of our team and the Cal Poly Pomona Industrial and Manufacturing Engineering Department, we want to thank the Steel Founders's Socitey of America for putting on the Cast in Steel Competition. Each and every one of us are extremely grateful to be able to participate in this competition. We want to give a special thank you to Kimberley Schumacher for always being accessible to any questions we had and for keeping us informed about any changes.

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We also want to thank Matthew Cefalo for helping our team get the 3D prints done on such short notice. Even though it was difficult getting the settings right, the prints we did have were absolutely awesome.

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