2020-2021 SFSA Cast in Steel Competition
Thors Hammer Technical Report

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Abstract

The idea of Thor's Hammer has existed since the 11th century, documented first on a Norse amulet and most recently in the ever-popular Marvel franchise films. The span of this existence has allowed for many changes to affect the general image of the hammer; therefore, our target for this project was the production of our own Thor's Hammer through casting. To achieve this goal, our team went through research, design, tooling fabrication, hammer production, final assembly, and testing.

1. Introduction

1.1 Project Management

For this project, we used the following Gantt chart in figure 1. This allowed us to properly schedule the project to finish in a timely manner, anticipating any issues we may encounter during the project. We started with bi-weekly meetings discussing the initial design, casting, product design, alloy, pattern, and producibility. As the project progressed, the team decided on a final design using a mix of all ideas given by the team. Due to complications of casting that were unforeseen, the initial design was scrapped for a more simplistic design that would be easily sand casted and produced.

TASK	PROGRESS	START	END
Research/Preliminary Design			
Proposal Rough Draft		10/19/20	10/ 30/20
Proposal Submission		10/ 30/20	10/31/20
Hammer Design		11/1/20	11/15/20
Handle Design		11/1/20	11/15/20
Pommel/ Guard Design		11/1/20	11/15/20
Prototyping			
Research of Alloy and Process		11/16/20	12/16/20
Tool Design		12/1/20	12/16/20
Gating System		12/1/20	12/16/20
Cast Prototypes (Hammer Pommel, Guard)		12/17/20	12/31/20
Final Design			
Approve Final Design		1/1/21	1/2/21
Post Process			
Gating System Removal		1/3/21	1/7/21
Heat Treatment		1/8/21	1/18/21
Creation of Handle		1/3/21	1/18/21
Polish and Rough Edges of Hammer		1/19/21	1/22/21
Assembly/ Submission			
Assembly of Thor's Hammer		1/27/21	1/30/21
Final Report		1/2/21	2/30/21
Submission		2/30/21	3/12/21

Figure 1. Original Gantt Chart

As the final design changed, the team updated the Gantt chart to a more plausible timeline as this caused multiple setbacks within our project. The final design was approved by all team members and this allowed the team to start printing a plastic prototype and a simulation using Solidcast as this would reduce scrap and increase productivity. The gating system and riser were designed and tested to complete the casting with the proper temperatures, and volume during the cooling stage. Once this stage was complete, the team created a 3D matchplate and assembled it to prepare for the casting process. After being casted, the casting was cut, sanded and finished to the desired look. Then heat treated for overall strength and ductility. Figure 2 refers to the teams updated progress of the overall timeline of the project done as the first timeline was inaccurate.

TASK	PROGRESS	START	END
Research/Preliminary Design			
Proposal Rough Draft		10/19/20	10/ 30/20
Proposal Submission		10/ 30/20	10/31/20
Hammer Design (weight and strength) Gating system		11/1/20	12/31/21
Handle Design (Weight and Strength)		11/1/20	1/15/21
Prototyping			
Brainstorm/Solidwork Hammer and handle Designs		1/15/21	1/20/21
Consider and choose final deisgn for green sand casting		11/16/20	12/16/20
Create Gating System (drags, risers in cope and simulate)		12/1/20	12/16/20
Print 3D modeland approve final Design		12/1/20	12/16/20
Cast Prototypes (Hammer)		12/17/20	12/31/20
Final Design			
Approve Final Casted Design		1/1/21	2/21/12
Cast Prototypes (Hammer)		12/17/20	12/31/20
Final Design			
Approve Final Casted Design		1/1/21	2/21/12
Post Process			
Gating System Removal		2/22/12	2/26/12
Heat Treatment		2/1/21	3/1/21
Creation of Handle		2/5/21	3/7/21
Polish and Rough Edges of Hammer		3/8/21	3/8/21
Assembly/ Submission			
Assembly of Thor's Hammer		3/8/21	3/11/21
Final Report		2/21/12	3/17/12
Submission		3/17/12	3/19/21

Figure 2. Updated Gantt Chart

1.2 Literature Review

When researching the history behind Thor's Hammer, the team decided to focus on the cutout of the original hammer from nordic mythology and Marvel's Thor. Although Marvel's Thor is a great representation, we focused heavily on Nordic Mythology as we were aiming to incorporate the story into the hammer's design. According to "*Norse*

Mythology for Smart People” the name “Thor’s Hammer” by usually brings the image of a big, powerful weapon to mind. According to the mythology of Thor’s hammer, this weapon was classified as a “Warhammer.” Our team’s question in response to this information was as follows: did “Warhammers” even exist? In medieval combat, yes; however, Norsemen like Thor didn’t use Warhammers until the Renaissance.

Furthermore, these hammers did not look like the widespread Mjölnir we know because common depictions of Mjölnir are based on blacksmith hammers(Mjollnir, 1). While this makes for a great movie image of a solid, chunky, powerful hammer that can cause immense damage, the majority of the Warhammers used in the early Medieval period looked remarkably similar to the classic hammer we know today: one flat, hammer-like side, while the other side is sharp and pointy to hook or penetrate metal. Occasionally, a spike on the top of the hammer was included to allow for stabbing motions as well as swinging. Generally, though, the hammer side was used since either of the pointed ends would get stuck in objects and need to be removed which took more time and effort, keeping warriors from hitting other people/things.

Figures 3 and 4. French Warhammer; Viking Iron Warhammer head

The anatomy of a Warhammer is very simple, yet effective. Single-handed Warhammers were most commonly used and were roughly 2 to 3 feet long, shorter than a one-handed sword. This smaller, less-obtuse form of the hammer was mostly used by fully-armored men against other fully-armored men in battle. The larger Warhammers or “pole hammers” would have been a maximum of 6 feet long and were used against riders. Hammer heads were forged out of higher quality steel; striking surfaces were forge-welded to create super-strong striking surfaces while the rest of the body was made of softer steel so as to not waste resources. Langets, an extra tongue of steel wrapped around the middle and attached to the upper handle, were extended from the hammer head to the handle to stop the head from coming off during repeated hits. The handle itself was simple and made of wood. While a larger, sledgehammer-like weapon would have been more intimidating and probably delivered more force in blows, they ultimately would not have been very effective in battle. The size and proportional weight would have started working against the wielder and fatigued them faster than the smaller, lighter Warhammers that existed. These hammers were the main defensive force in battle among the large population of people partaking, so the durability of the weapon was especially important and was shown in the care taken to reinforce specific parts.

Figure 5. Images found by the team used for inspiration for Hammer Design.

2. Design

2.1 Design Selection

When our team approached this project, we identified two main paths of design we could take: mythologically-based or Marvel-franchise-based. After discussing both options, we decided to follow more of the historical narrative because we felt it allowed for more freedom within the added details. We chose to incorporate most of the original shape of Mjölnir (Thor’s hammer) as we wanted to hold on to the main idea and symbol of the hammer, as it represented not only a destructive weapon but a symbol of protection and security from the evil and violent forces and now is used to depict heroism.

To include our own individualism and flair to the design, we weaved this image (refer to Fig. 6, far left) of the hammer (an anchor shape) into the design, first as a cutout through the hammer head and then as a subtle engraving in the final design. We chose to take the original Nordic hammer and modify the design by adding fillets on the right and left faces to reduce overall surface area, therefore, creating less impact throughout the hammer shown in the Figure below (highlighted in the red circles). We also extruded two arcs (highlighted in blue) on the front face to lessen the overall weight of the hammer and include other designs of the hammer. We used the front face to convey the true story of Thor's Noble position as told in history. In the middle, the team decided to use the "Triquetra" as this was heavily seen and used in Nordic culture to signify the base of Thor's Story as it symbolizes Asgard, Midgard, and Utgard. From there on we extended it out to two arcs, and a square design highlighted in green circles. This is an abstract version of a doorway that symbolizes the beginning and end of Thor's Journey. In the middle of the hammerhead itself, we used an abstract version of a raven as ravens were inspired by the messengers in nordic mythology that relayed messages to Odin.

For the handle, our group wanted the hammer to appear as worn and splintered as if it were carried by one who has undergone a lifetime journey. Therefore, four main features were examined and applied. These were the size of the hammer, color of the handle, carvings, and resin. For size, our group was considering intentionally making the handle short. The shorter handle was considered because of the size significance in the Norse mythology of Mjölnir. According to folklore, Loki, Thor's brother and god of mischief, meddled with the dwarves who were constructing the hammer. This resulted in the entire hammer, especially the handle, dwindling in size. It was this that apparently gave the hammer its power.

2.2 Alloy Selection

When considering the alloy, the team took into consideration the alloys provided by the Soundcast Co. foundry by the following: perspective weight, fracture toughness, ductility, hardness, and compressive strength. With all of these in mind, the team decided to use Heat treated 4130 Steel as we wanted the hammer material to be able to withstand multiple blows from a hard object without breaking or deforming and from also receiving insightful feedback from the Foundry lead, Jason from Soundcast. With a Tensile strength of 560 MPa , yield strength of 460Mpa and Modulus of elasticity of 190-210 GPa, this was the best option for our uses.

2.3 Production Processing Selection

During the beginning of the project, the team decided to use sand casting in the construction of our hammer head. This allowed our members to better learn and truly understand the process of sand casting and the roadblocks that others have faced during the overall process.

The sand casting required a 3D printed pattern, a matchplate, and the top and bottom flasks of the box in which casting was to be done in. Before the actual sand casting project, we were able to build a 3D model through Solidworks and simulate on SolidCast in order to create match plates to identify the best possible design without compromising key design components, the weight of the hammer head, the composition, and the cost efficiency of the actual hammer itself (Casting Source).

The basic process consisted of these six steps:

1. Place a pattern in sand to create a mold
2. Incorporate the pattern and sand in a gating system
3. Remove the pattern
4. Fill the mold cavity with the molten metal
5. Wait and allow the metal to cool
6. Break away the sand mold and remove the casting

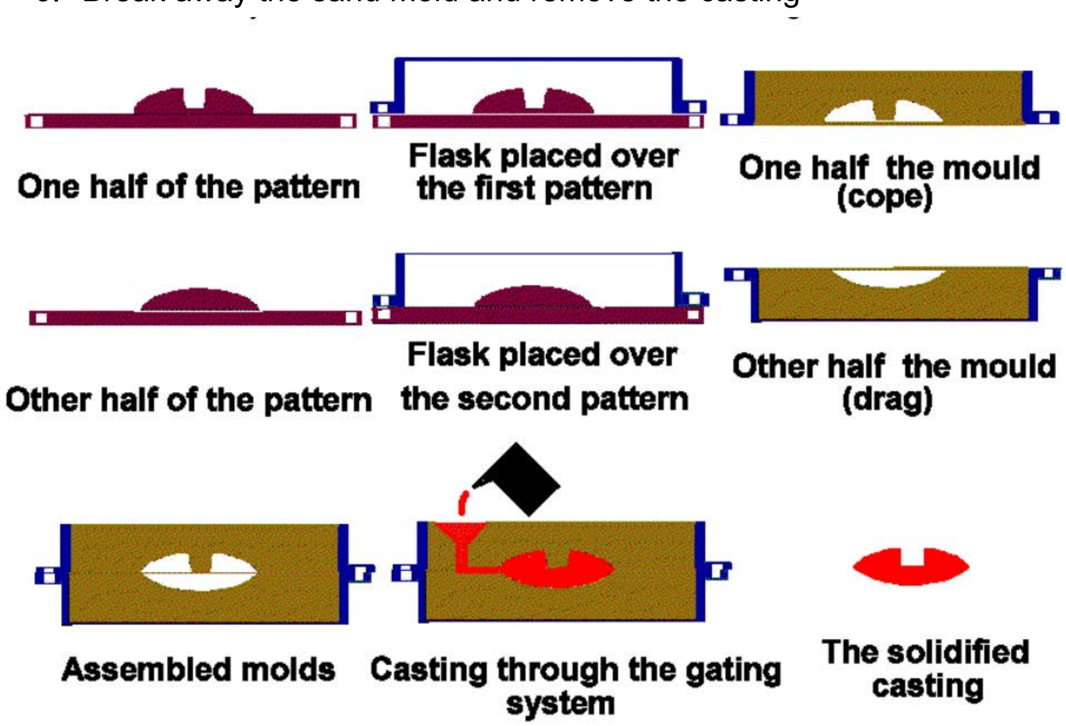


Figure 6. Basic Process of Green Sand Casting of Steels

3. Manufacturability

3.1 Initial Design Analysis

During this phase of the project, the team used Solidworks to bring our idea to life within the design proposal and the restrictions of sand casting. To combat these parameters, we asked ourselves a multitude of questions. For example:

-How will green sand casting affect the design?

-Will the design be durable and aesthetically-pleasing while keeping true to the Theme and story of the hammer?

- Does the design of the hammer fit the parameters leaving room for error (ie. size and weight)?

With these questions in mind, the team was able to brainstorm for our designs. Initially we had about 7 to 8 designs. Figures 7 - 14 shows the progression of the Thor's Hammer. During this time, we were trying to have a firm grasp of how the casting will affect the actual casted part as there would be alot of room for error. Half the team wanted to go for a simplistic look that would be sturdy and safe whereas the other half wanted to have a crazier design, i.e. resin and fairy lights within the hammer head itself to keep to a mythological feel when holding the hammer. Resin could cause issues when testing out the hammer as it could be easily damage due to blunt force.

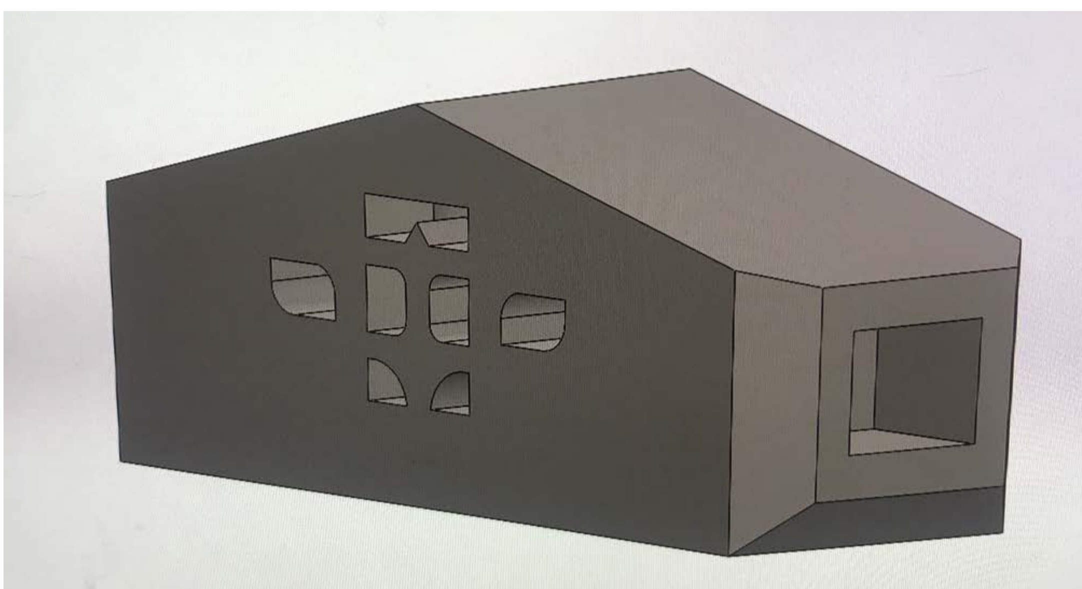


Figure 7. Image of Prototype 1

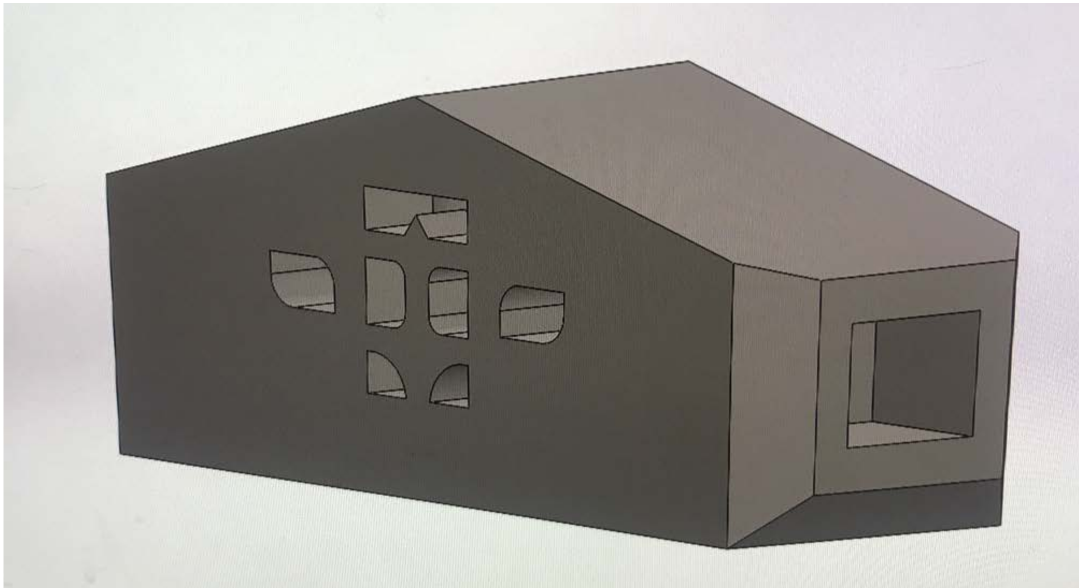


Figure 8. Image of Prototype 2

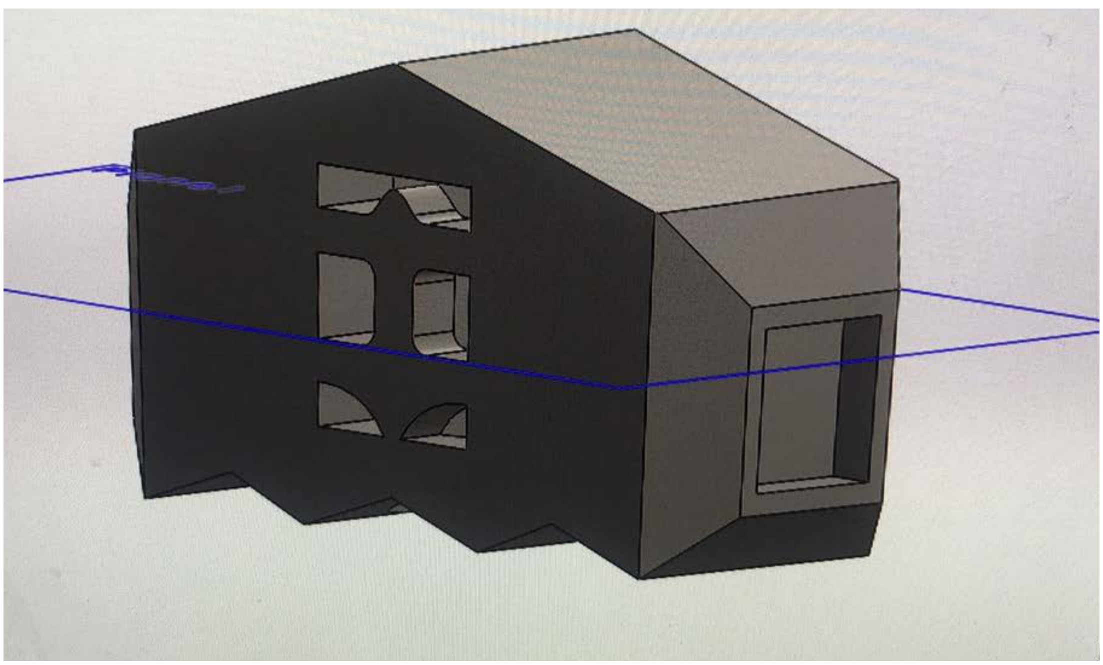


Figure 9. Image of Prototype 3

Figure 10. Image of Prototype 4

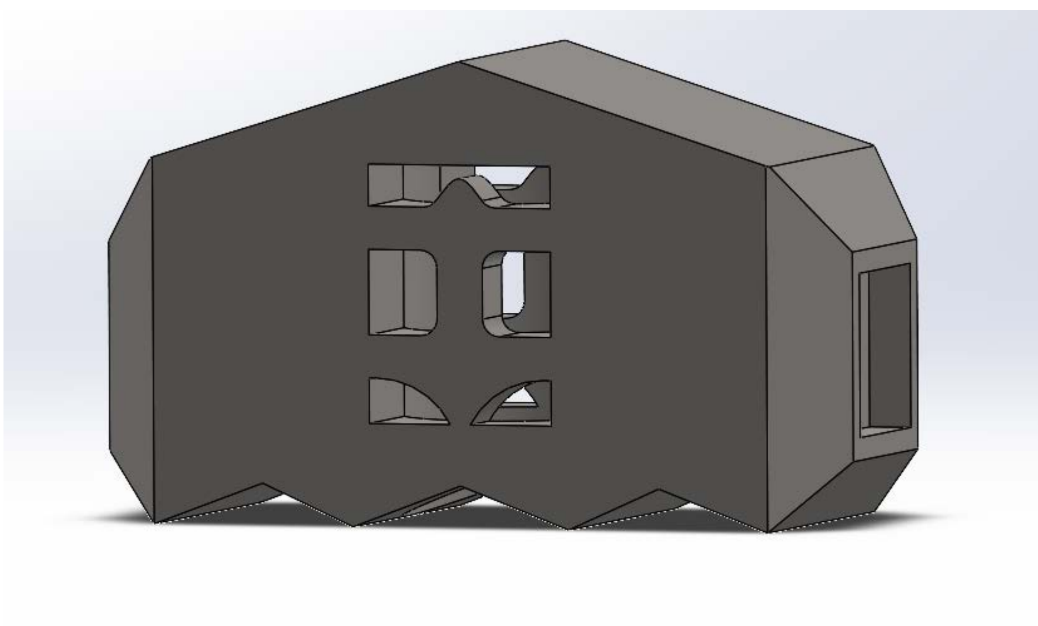


Figure 11. Image of Prototype 5

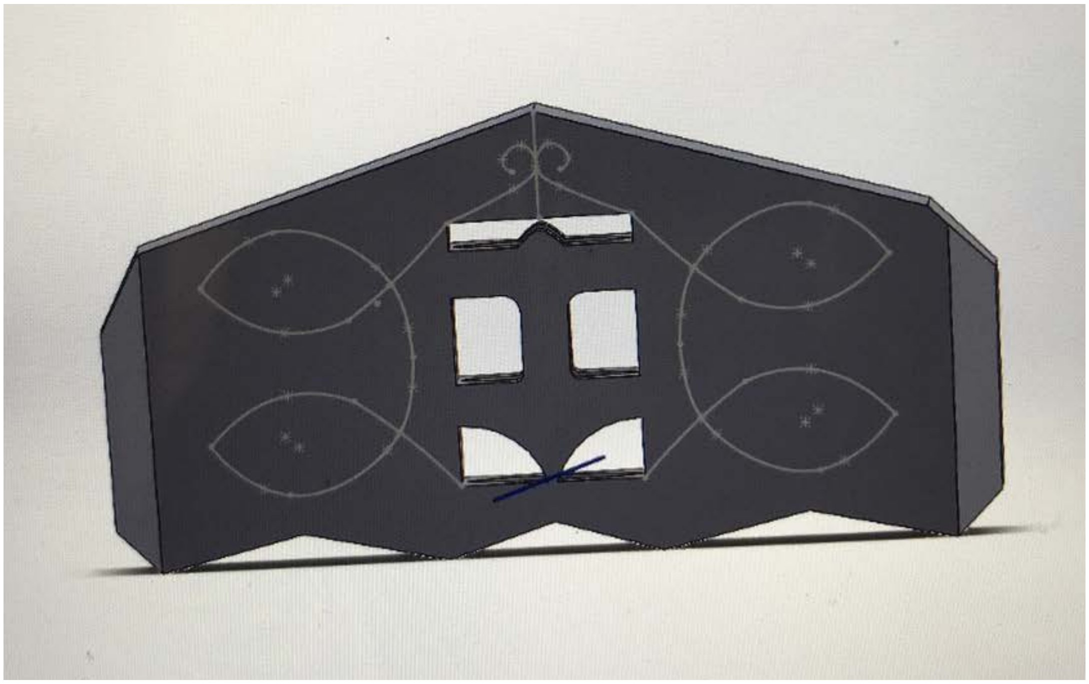


Figure 12. Image of Prototype 6

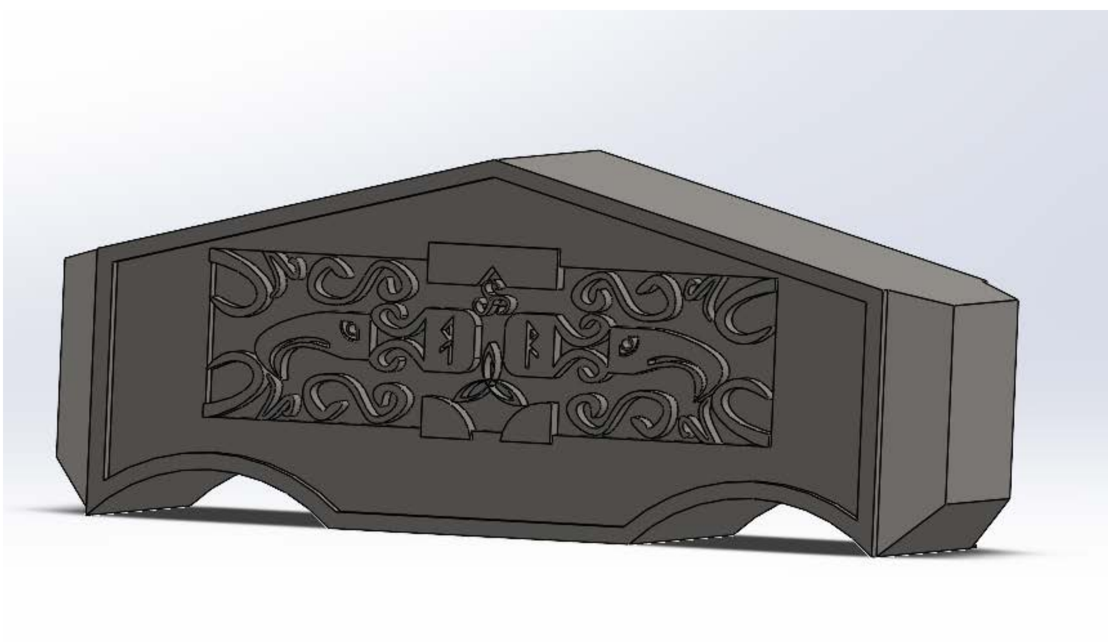


Figure 13. Image of Prototype 7

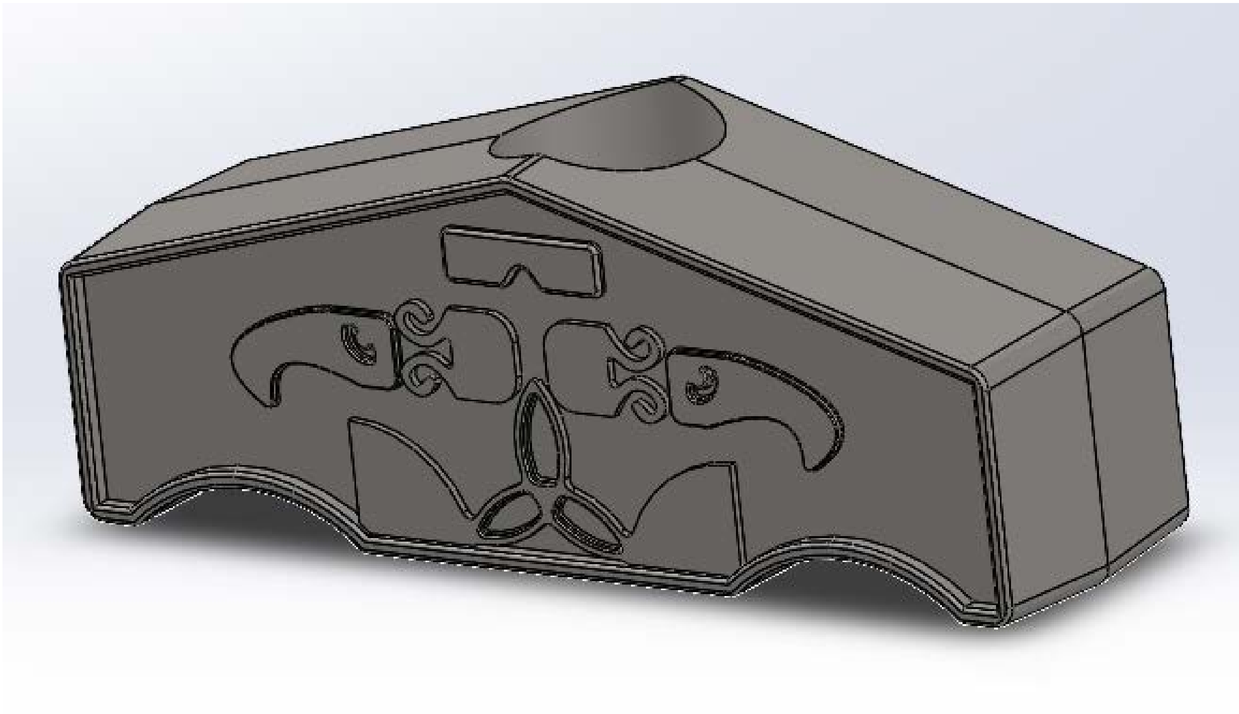


Figure 14. Image of Prototype 8

As these prototypes satisfied the requirements, we were unsatisfied with the design. To include our own individualism and flair to the design, we weaved this image (refer to Fig. 5, far left) of the hammer (an anchor shape) into the design, first as a cutout through the hammer head and then as a subtle engraving in the final design. We chose to take the original nordic hammer and modify the design by adding fillets on the right and left faces to reduce overall surface area therefore, creating less impact throughout the hammer shown (highlighted in the red circles). We also extruded two arcs (highlighted in blue) on the front face to lessen the overall weight of the hammer and include other designs of the hammer. We used the front face to convey the true story of Thor’s Noble position as told in history. In the middle, the team decided to use the “Triquetra" as this was heavily seen and used in Nordic culture to signify the base of Thor's Story as it symbolizes Asgard, Midgard, and Utgard. From there on we extended it out to two arcs, and a square design highlighted in green circles. This is an abstract version of a doorway that symbolizes the beginning and end of Thor's Journey. In the middle of the hammerhead itself, we used an abstract version of a raven as ravens were inspired by the messengers in nordic mythology that relayed messages to Odin

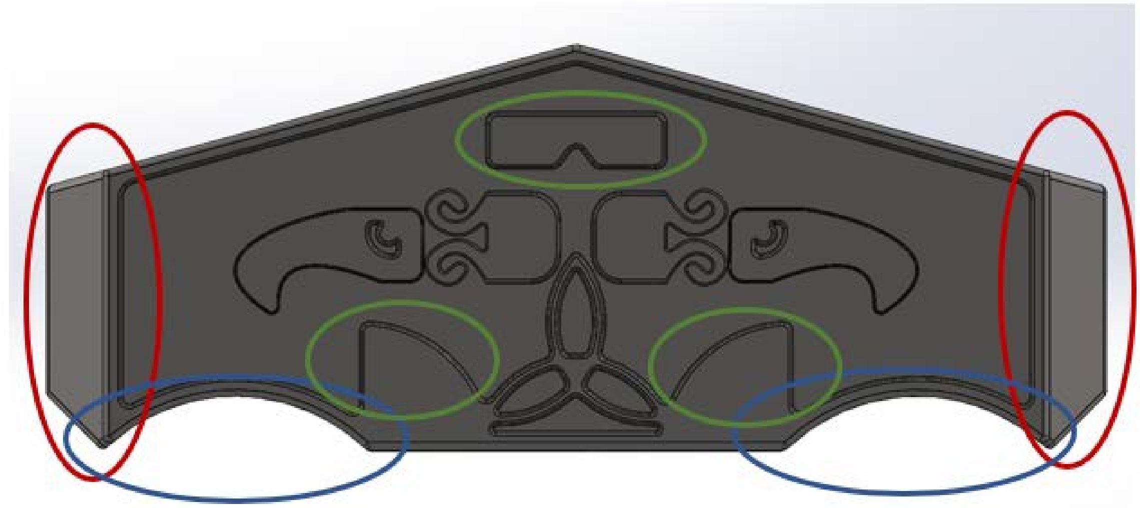


Figure 15. Team's 3 original Solidworks design.

When creating the handles design, we wanted to keep to an easy design that would be simple and sturdy that will match the theme of the head. To do so, the team initially opted for a handle that was about 1 inch in size and about 6 to 20 inches in length. For the color, the sample wood was stained and tested (as seen in figure 6) between Provincial 211 (top half) or Red Oak (bottom half). After giving thoughtful reflection, the team agreed upon Red Oak for the stain of choice. For carvings, the group wanted to include Norse symbols, also known as "Runes", and any other element that would add story to our hammer. For runes, we selected the symbols (as seen in figure 7) that translated, "War" (top) and "Journey" (bottom). On the other side, a carved lightning bolt was implemented into the design, the carving of the lightning would then be filled with a blueish-white Epoxy Resin to give it an effect of lightning cracking into the hammer handle (as seen in figure 16 and 17).


Figure 16. Testing wood used for test staining, carving, and resin casting


Figure 17. Rune Carvings of test hammer handle

Figure 18. Resin Casted lightning in test hammer handle

The handle itself also went through many changes as the team couldn't decide whether to use a shorter or longer handle. The decision for longer handle proved important because this aspect would not only affect the overall look, but also the ergonomics of the actual hammer itself; the impact of the handle on the hammer's head was a large factor in our decision since it would become imperative when testing. For the carvings, an additional Rune was added which translated as "Growth" (bottom of figure 11). Adding this additional Rune helped fill out the space of the handle and also gave an added meaning to the message behind the hammer, a warrior or one who partakes in ongoing war going through a lifelong journey to end in a growth of themself.

Figure 19. Rune carvings in final hammer handle

As for the sizing and length of the hammer head and handle, the head itself is 6 inches in length, 1.5 inches in width, and 2.27 inches in height. This allowed us to keep between 4lb-5lb parameters in weight as the team wanted to account for any last-minute changes in alloy or shrinkage during the casting process.

3.2 Final Design

The overall final Hammer design was a simplistic version of what we originally had as we had to be weary of the casting process itself and how the steel would form within the mold. The frame of the hammer stayed consistent throughout the entire design portion of the project whereas the designs on the face of the hammer changed significantly. The frame was designed to be able to withstand multiple blows with the triangular shape at the top of the hammer as well as the right and left sides.

Figure 20. Team’s 3 final design with handle

3.3. Pattern Design and Production

When using solidcast, the team was able to simulate the casting process to test what was the ideal temperature and density for the finished product. Since most of the team members were inexperienced with solidcast, we ran into numerous issues. For example, we were unsure how the actual gating system would actually affect the casting itself. Figure 21, is the first simulation done by the team.

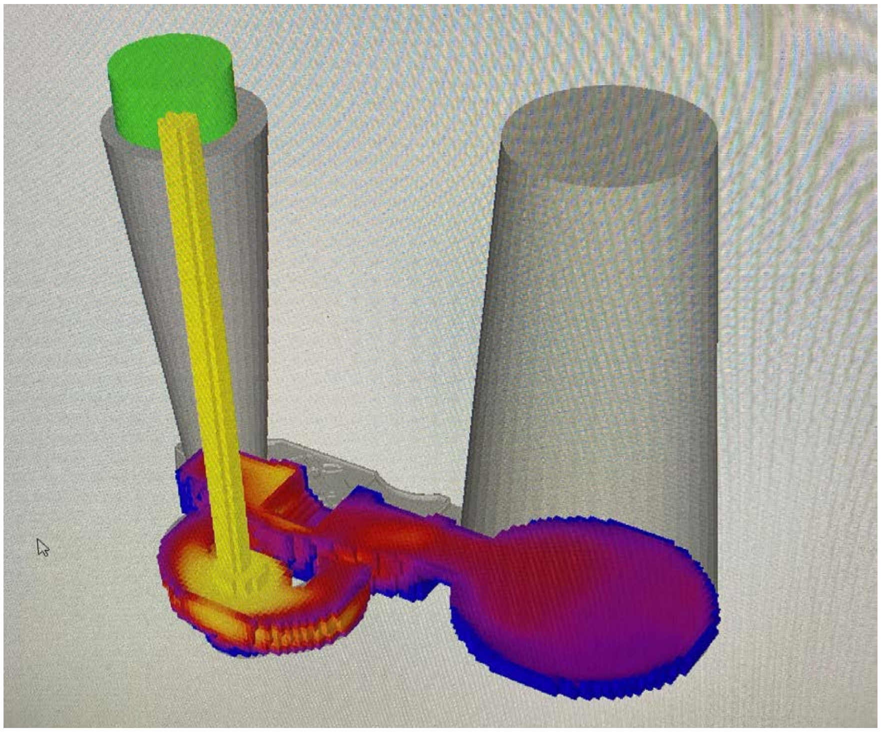


Figure 21. First test of simulation of solidcast

Based on the simulation, we originally sought out to attach the hammer’s head to the cope but, we noticed that the temperature was cooling down too quickly, creating shrinkage in the middle. To prevent shrinkage, we created a draft in two different angles so the material can flow through in two different areas as well as the cope and drag. We tested out a circular entry and a rectangular entry to demonstrate the flow within the riser of the gating system. As we had presumed, the circular entry allowed an easier and smoother downpour of steel into the mold itself as shown in figure 22. The new gating system allowed for two hammer heads and realistically, a better solidification of the product.

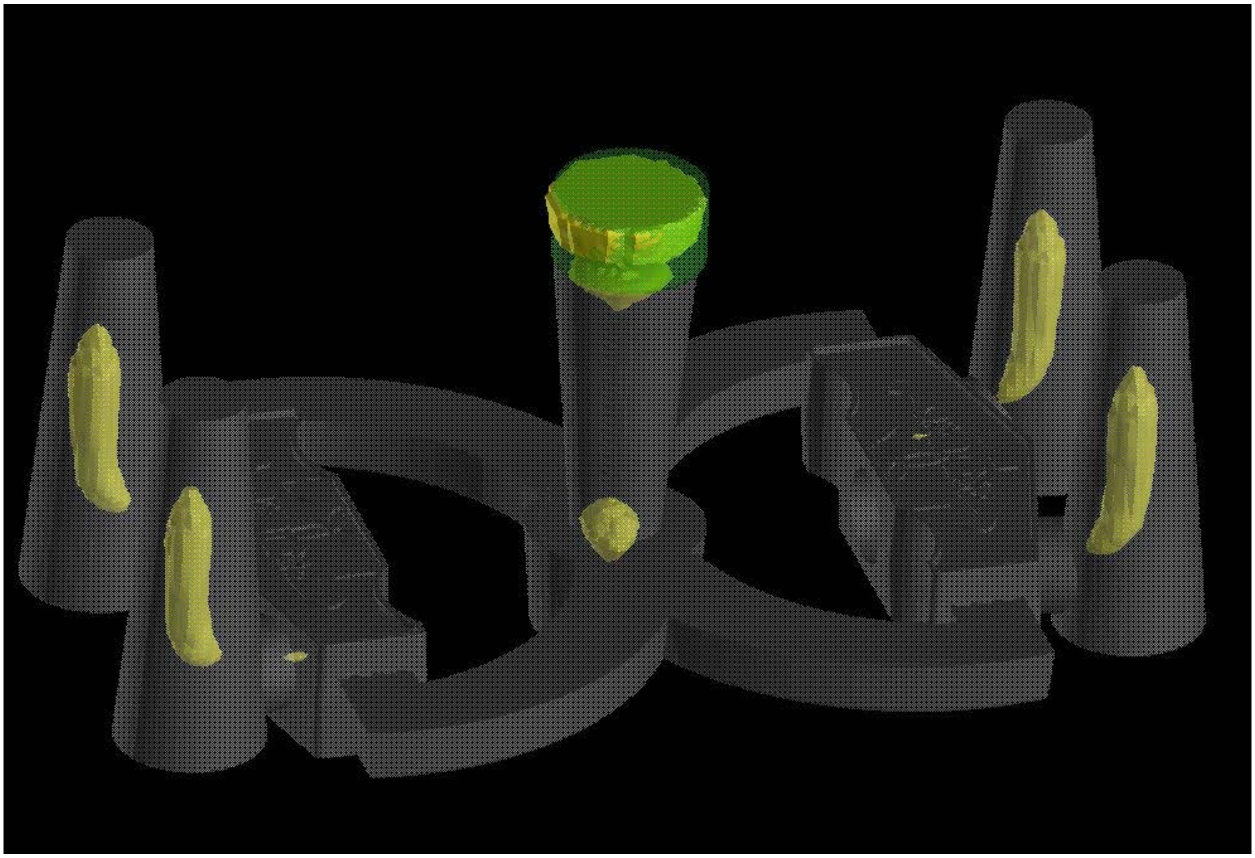
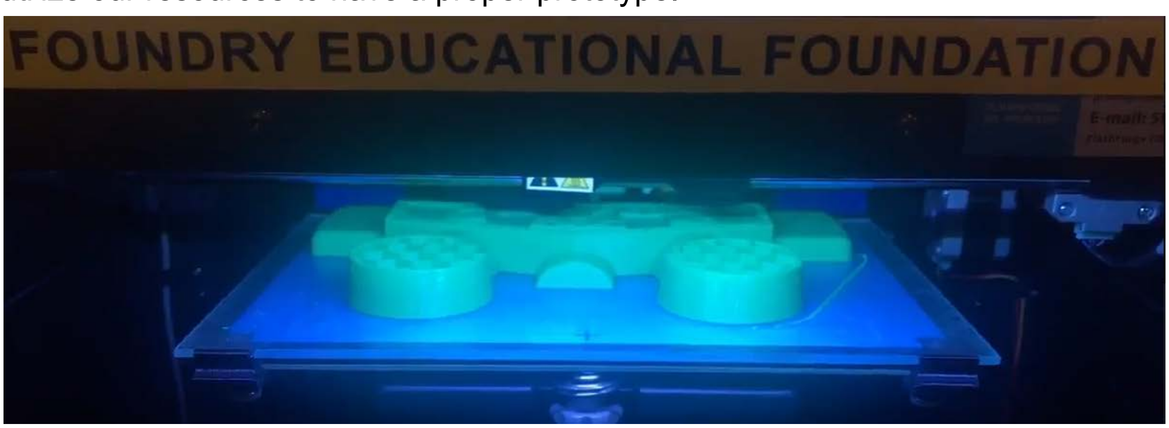


Figure 22. Final simulation of Solidcasts without little to none shinkage.

3.4 Prototyping

As the team had no access to Cal Poly Pomona’s Casting Lab, we were unable to fully utilize our resources to have a proper prototype.



3.5 Production Processing

As there was no prototype, this made a path for the team to research what were the best ways to produce this head with the least amount of resistance with the help from Jason from Soundcast. Jason and our Team Lead, Rob were able to insert the actual 3D mold and continue the process. Unfortunately, during this time, the matchplate was not sturdy. The match plate was glued down but in this situation, it would not hold, so instead, we used screws to fix this issue and move forward with the casting. The pattern was destroyed but we were able to get at least 2 molds as shown in the figure below. Fortunately, the hammer head produced came out with minimal shrinkage although there were issues with the design itself, we were able to sand out the rough edges to achieve a more desired design that is referred to in the figures below.

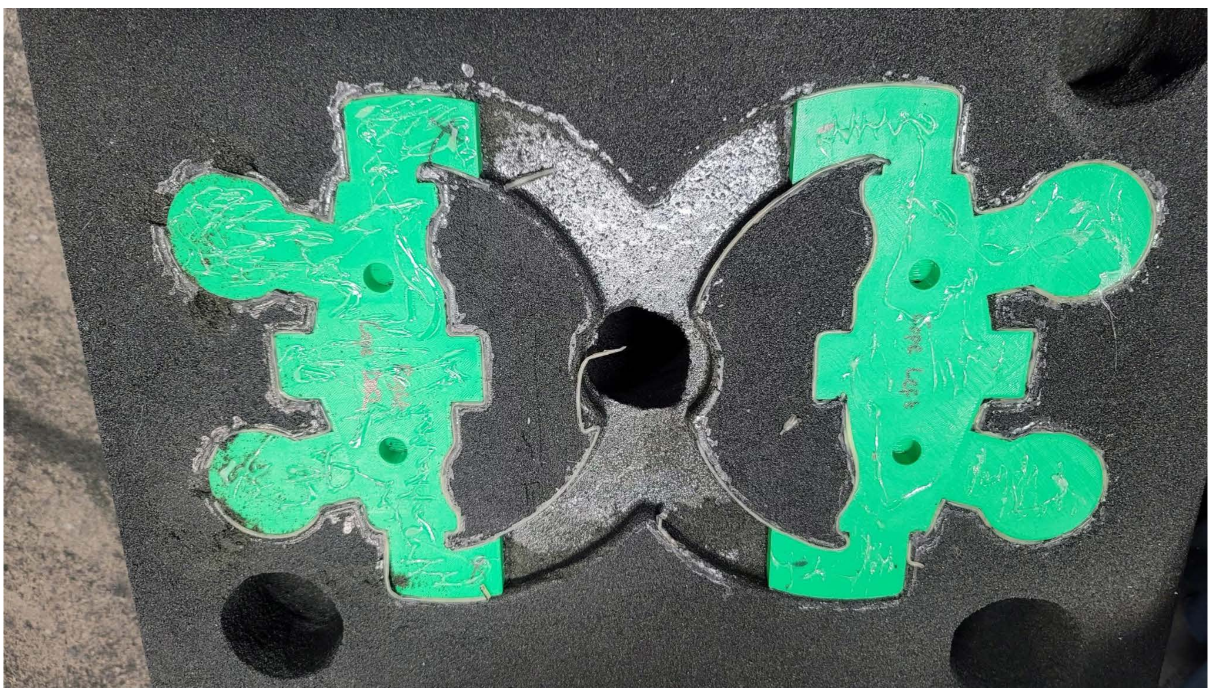


Figure 23. 3D Printed mold inserted into the sand to be used for the casting process

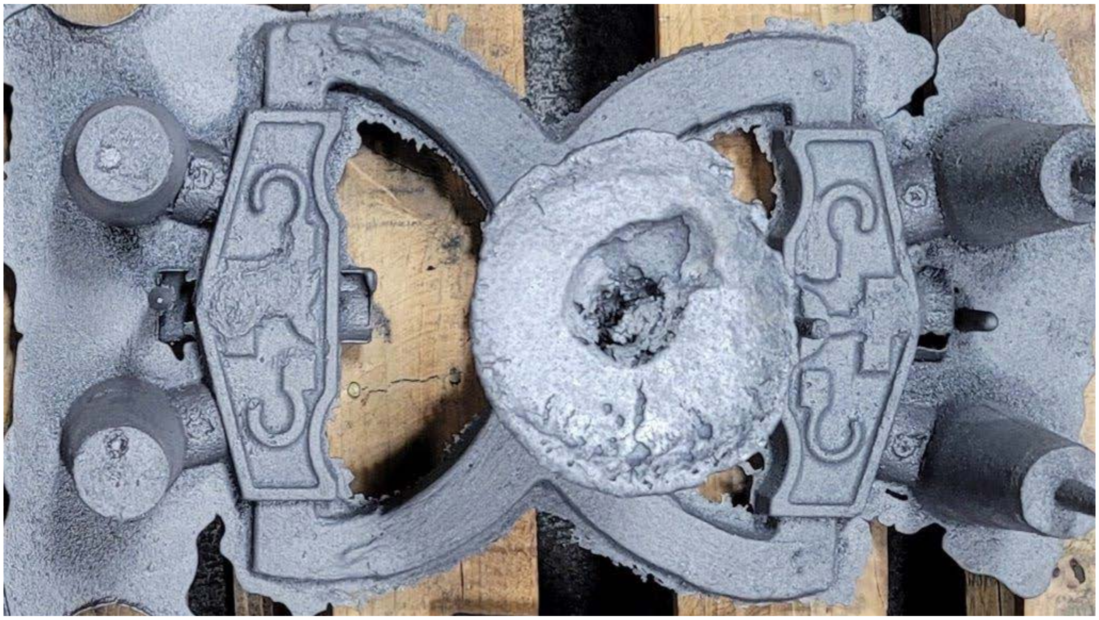


Figure 24. Image of pre-cut casting

Figure 25. Hammerhead before sanding down sharp edges

Figure 26. Front View of Thor's Hammer Head

Figure 27. Final product of Thor’s Hammer Head

4. Quality and Performance

Table 1: Chemical Analysis

Heat No.	C.	MN.	SI.	P.	S.	CR.	MO	FE	QTY.
B32626	0.30	0.48	0.30	0.015	0.022	0.98	0.23	BAL.	1

Table 2: Physical Property Data

Heat No.	Tensile PSI	Yield PSI	% Elongation
B32626	156,879	117,301	9.0

Table 3: Heat Treatment

Process	Temperature	Time	Quench Medium
Austenitized	1660 F	2 Hours	Water
Temper	1100 F	2 Hours	Air Cool

Note: Specifications: ASTM A732 GR. 7Q (4130); Material: Steel

All the analysis was provided by Jason. With all the process the Hammer's Head went through, it was no surprise the hammer itself was sturdy and high quality. The austenitizing and tempering process allowed the steel to transform the 4130 steel to the full hardness the team was aiming for as we wanted the hammer to withstand multiple blows.

To test the team hammer's quality, we performed numerous tests with items we had readily available. For these tests, we used a variety of materials that had high compression strength, were dense in section thickness, and were accessible. Using cement plates, a car bumper from a hyundai elantra, and fruit, we were able to see how much force we were able to apply to the hammer and item itself. Throughout all the tests, we were happy with the final outcome as there was no damage to the hammer itself. It was able to withstand all the heavy blows to different materials.

5. Conclusion

The SFSA Thor's Hammer competition was a great opportunity to utilize and apply all the information given to us throughout our years at Cal Poly Pomona. As we went through with the designs we learned so much with the restrictions on sand casting and how overall types of steel will affect the casting process which was simulated for us. In future processes, the team reflected on how we would be able to improve the hammer in sand casting by looking at alternative forms of sand casting and steels as this would greatly affect the ductility, hardness and design of the finished product.

This competition was a great experience in project management and team working as we were challenged with the tasks of fulfilling this project with COVID-19 as this required more timing and alternatives compared to other years. We now know how to maneuver projects like this in the future and it provides more opportunity for hands-on learning for our team.

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