Cast in Steel Competition 2021

Thor's Hammer Final Report

Team Members
Nathaniel Lies
Greg Wong
Esteban Nava Sanudo
Kenna Ashen

Advisors
Dr. Ankit Srivastava

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Team Members

Nathaniel Lies - I am a senior MSEN student at Texas A&M and I am the project lead and main fabricator of the hammer! Whoop!

Greg Wong - I am a senior majoring in MSEN at Texas A&M and I produced the videos and did research for the hammer! Whoop!

Esteban Nava Sanudo - I am a junior MSEN student at Texas A&M and I worked on the CAD for the hammer! Whoop!

Kenna Ashen - I am a junior majoring in MSEN at Texas A&M and I designed the artwork and did research for the hammer! Whoop!

Abstract

For the 2021 Cast in Steel competition, our team was tasked with designing and producing a replica of Thor’s Hammer. This hammer, named “Mjolnir”, was said to be one of the finest weapons ever created except for its short handle. Countless amulets depicting Mjolnir have been found in graves and carvings across northern Europe and Russia. We focused our design on the rich history, art, and myth of ancient Norse culture. We designed the hammer head, handle, and pommel and in Solidworks to be around 5.5 lbs. To keep the hammer light without compromising its strength, we decided to create a hollow shell for the head and fill the cavity with a wood block. We used a variant of 4230 steel for the head and pommel because it is tough, hard, wear resistant, and easy to weld. We hand-drew designs depicting different elements of Norse mythology and used Solidworks to inlay the designs on the head, handle, and pommel. For casting, we decided to use investment casting for its high print resolution and surface finish as compared to sand casting. With the help of the American Foundry Group in Oklahoma, we casted 2 hammer heads and had them heat treated and the faces carburized. We chose oak for our handle because oak was considered especially holy to Thor. We etched designs into the handle, sealed it with linseed oil and combined all of the components into our final hammer.

Figure 1. A Mjolnir amulet. The runes inscribed in the left image read “This is a hammer.”[1]

Introduction

In this project, a replica of Thor's Hammer was designed and manufactured with specifications given by the Steel Founders' Society of America (SFSA) for their Cast in Steel competition. The Cast in Steel competition allows for college students to apply their knowledge of computer modeling, alloy development and selection, additive manufacturing, and casting techniques to make a complete product.[2]

Two main design specifications were given to us by the SFSA. First, the hammer must weigh no more than 6 pounds. Second, it must be less than 20 inches in length.

A sledgehammer generally consists of a large metal head and a long wooden handle. The head is usually a rectangular prism. Depictions of Mjolnir show a trapezoidal head and short handle instead. These deviations from typical hammer design make for an interesting design project and leave a lot of room for innovative design.

Historical Background

In Norse mythology, Thor is the god of thunder, as well as a fertility god. He wielded a hammer called Mjolnir, said to be one of the finest weapons ever created. Its only flaw was an unusually short handle. Mjolnir was used for both blessing and destroying. While many modern interpretations of Thor focus on his warrior side, a good example of his fertile and protective side are his two goats who he could kill for food and revive the next day, provided the bones were intact. Finally, Thor was particularly protective of humans. Thus, Mjolnir became a popular symbol of both fertility and protection.

Natural spaces were considered holy. Worship was done primarily outside in untouched forested areas. Oak groves were considered uniquely important to Thor and were often treated as spaces of safety and refuge.[A] Not only were natural groves sacred, but the universe itself was said to consist of nine "realms" connected by a mighty tree, Yggdrasil. At the top, where the realms of the gods were, lived an eagle and four stags who ate the tree's leaves. Many snakes live around the base, along with a dragon that gnaws on the tree's roots. A squirrel runs up and down the trunk, carrying insults between the eagle and the dragon.[3]

Vikings were skilled craftsmen who used wood for everything from practical ships and houses to decorative art and furniture. Many oak things have been found in archeological sites, such as oak stools, spatulas, pot lids, buckets and rakes.[4] Thus oak was not only important spiritually but as a physical resource as well.

Hammer Design

The design of this hammer was primarily focused on striking the balance between large and comfortable to use. To achieve the wanted size and to comply with the 6 pound weight limit, we decided to create a composite hammer head. To do this, we made the inside of the hammer head hollow. As a hollow hammer head isn't very strong, it will be filled with a different, lighter material to increase strength.

With these conditions in mind, the design's geometry was tweaked in Solidworks until it was perfect. To fully embrace the traditional nordic theme, the head was given a subtle curve along its length. The striking faces were also given a slight curvature. Most notably, the top of the head was given a curved slope that peaks at the middle to mimic the trapezoidal shape found in Thor's hammer amulets.

Ornamentation

Norse art features looping and interweaving designs similar to Celtic art, although it has a less uniform layout. Designs focus on animals shown in profile. The Jelling style, used from 900 to 975 CE, was characterised by its curled snarling lip, filled body, round or almond-shaped eyes, and spirals marking major joints. The Mammen style, from 950 to 1025 CE, featured many of the same elements as Jelling designs. However, the Mammen style introduced both more realistic and more stylistic designs. The style utilized more scrolls, tendrils, and more complex shapes. Animals became more anatomically correct as well. [5]

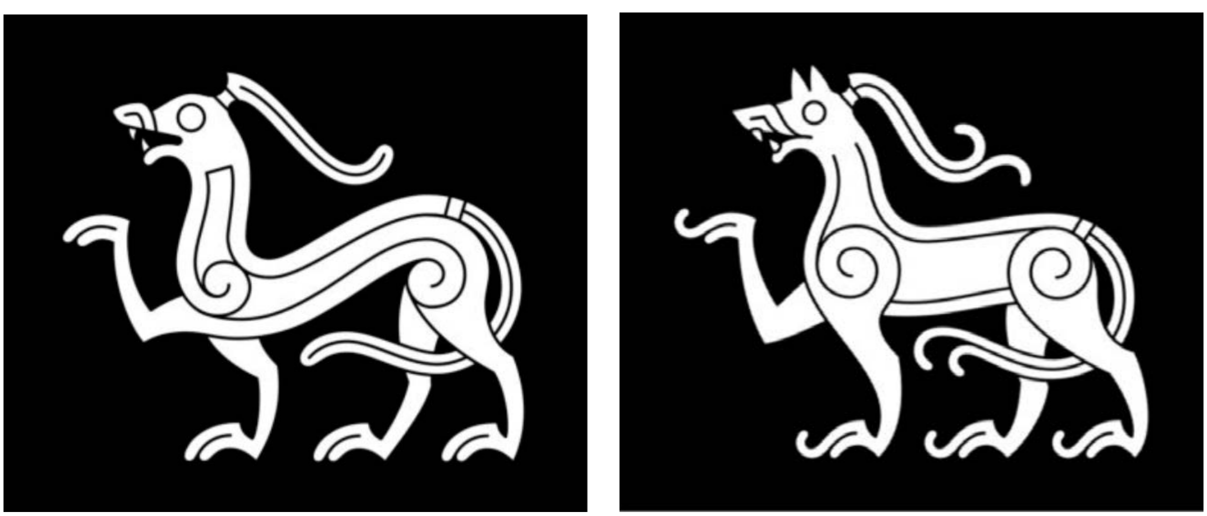

Figure 2. Comparison of Jelling (left) and Mammen (right) styles[5]

Because small details are difficult to cast, the Jelling style is ideal for casting. However, the Mammen style's increased realism is better for depicting the wide variety of creatures we wanted to show. Therefore we decided to use a mixture of Jelling and Mammen styles to balance both simplicity and variety.

We decided to design our Thor hammer as an illustration of Yggdrasil. To accomplish this, we placed images of the animals that live in the upper branches of Yggdrasil on the head of the hammer. The oak handle is the trunk of the tree. Finally, the pommel has images of a dragon and a snake as it represents the roots of the great world tree.

We took screenshots of our hammer design in Solidworks and drew out rough sketches of our design on the image of the respective faces. We measured the thinner segments to ensure they were wide enough to safety cast. Once this was confirmed, we assigned each section to one of three layers. The three layers were separated into three files and uploaded into Solidworks, where we inlaid each distinct layer onto their respective faces.

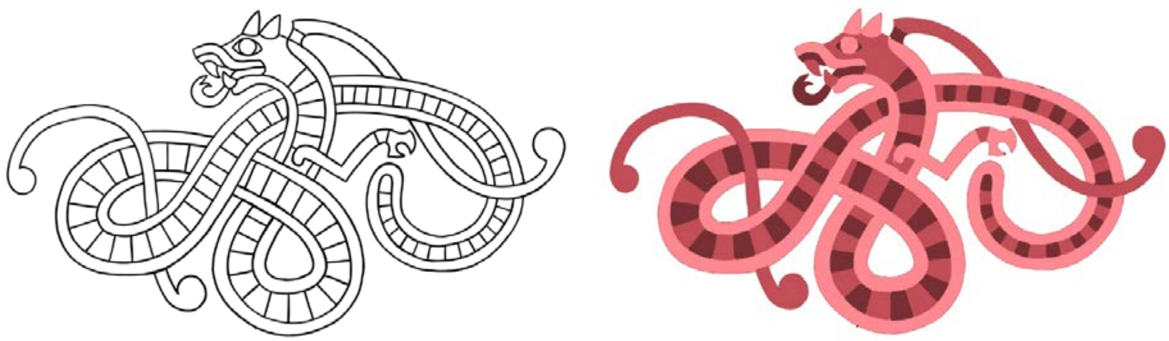

Figure 3. The design for one face featuring the dragon around Yygdrasil's base. The initial outline (left) was divided into layers and filled with color to mark each layer (right).

We used a similar method to design a pattern for the handle. However, because the handle was shaped by hand, we were not able to size the image as easily. To continue our Yggdrasil theme, we designed a pattern that looks similar to oak bark. We used a carved wooden handle from the Borre period (875-950 CE) as a guide. First, we simplified and loosened the weave of the lines. This both replicated the pattern in Jelling style and ensured that it could be easily adjusted to fit the unique shape of the handle. In addition, we wrote "Texas AM" and "Aggies" in runes on the sides of the handle to pay homage to our school.

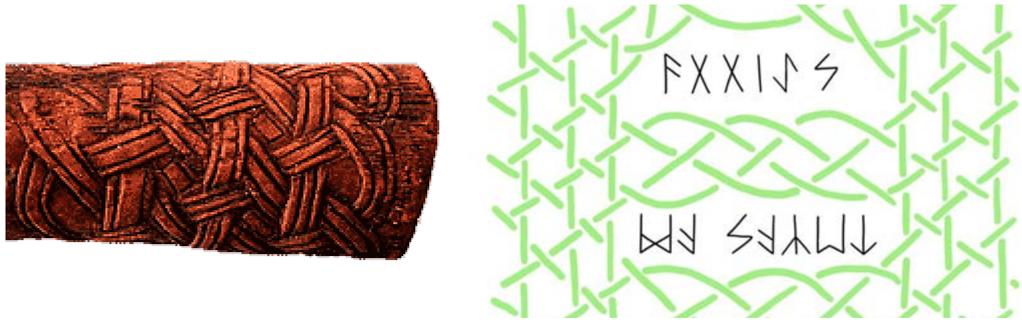

Figure 4. A Borre-style wooden handle (left) [4] and simplified Jelling design with runes (right)

3D Modeling of the Hammer

Once the hammer was finished out with historical proportions and geometry, the hollow hammer idea was implemented. First, the inside was hollowed out by cutting out material from the bottom of the hammer head. Then, coverings were made for the cavities.These coverings were then to be welded onto the hammer to create a hollow interior. These features can be seen in Figure 5 below.

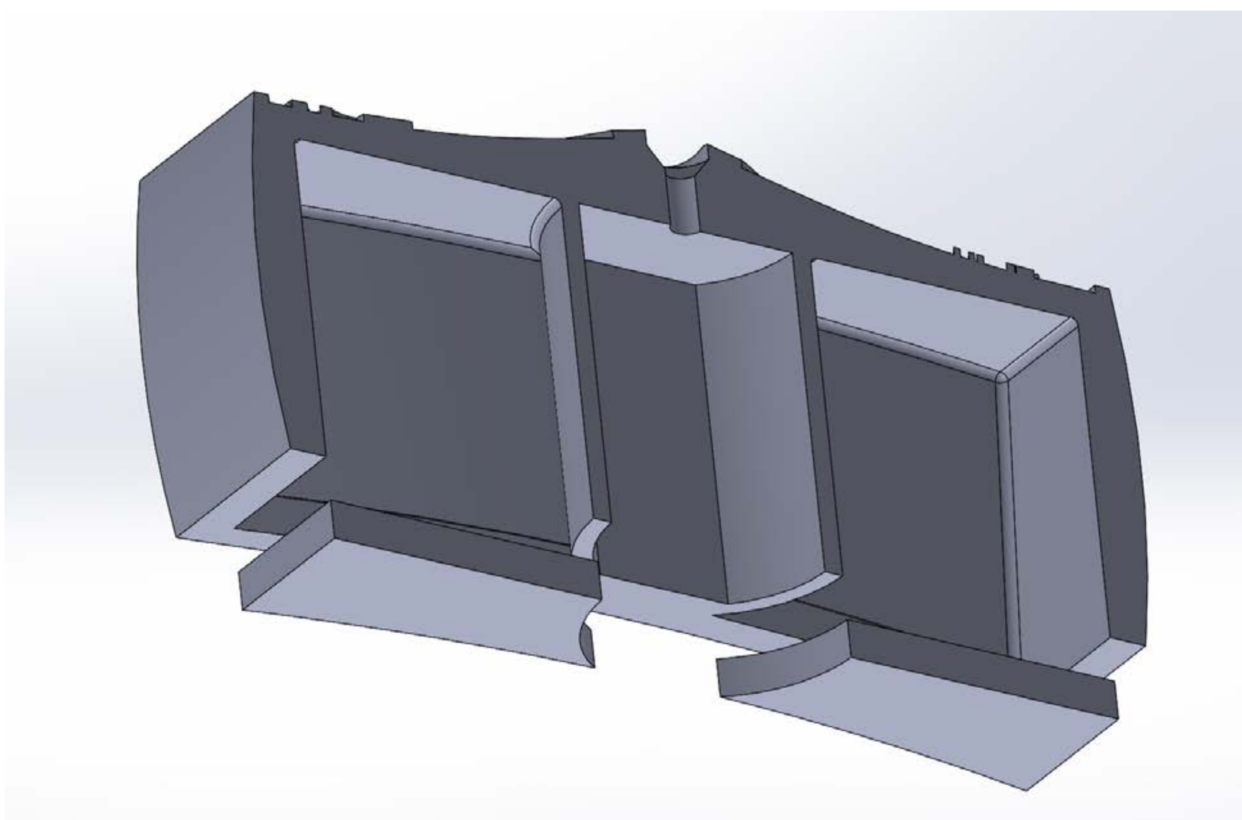

Figure 5. Cross section of the hammer’s head and bottom covers.

Along with hollowing out the hammer, the handle and pommel were added to the model. To attach these main components together, countersunk holes were created at the top of the hammer head and at the bottom of the pommel. The purpose of these holes is to allow for screws to reinforce the epoxy that will hold the hammer together.

For the finishing touches, the ornamentation was added into the CAD. This step was not only to decorate the model but also to allow the 3D printing of a wax model with the art already in place. With this wax model, casting the ornamentation in full detail became possible.

Figure 6. Full ornamentation in CAD for cast components.

Casting Optimization and Design Approach

As previously mentioned, the ability to cast the hammer in full detail relies on printing a wax model. However, there are still limits to investment casting. To retain a high resolution and as much detail as possible, the first step is to design within the limits of this wax model. To do this, the faces that contain the ornamentation were recessed 0.05 inches. The ornamentations themselves were then brought back up from the recessed faces to be level with the original face.

Additionally, the ornamentation designs were kept at a thickness of at least 0.05 inches as well. This was done to stay inside the resolution constraints of the investment cast. Lastly, many of the interior edges were fileted to reduce the possibility of mechanical fracture.

Material Selection

When we started our investigation into steel types, D2 tool steel was the top contender for our hammer. However, after talking to our sponsors, we learned that D2 is hard to weld. Due to this fact, we decided to change to B10.

To make the head composite, the cavities were going to be filled with oak because of its historical symbolism and good mechanical properties. However, the cavities were accidentally sealed with the cast covers before the oak was placed inside. Consequentially, the cavity had to be filled with something that could be placed inside without completely ruining the head. Epoxy was chosen. With small holes in the design, the cavities could be filled. Epoxy would be about twice the density of oak, but there was enough extra weight in our design to accommodate the change. However, the epoxy was later left out of the design due to concerns about overall comfort when wielding the hammer.

Heat Treating Process

The hammer was heat treated as per the foundry’s recommendation. The metal was also carburized 0.060 inches into its surface. This increased the surface hardness to 62 Rockwell C as per a test coupon that was heat treated in tandem with the hammers. This process ensures that the surface of the hammer is tougher than its as-cast condition meaning it will resist scratches and abrasion in intensive mechanical testing.

Fabrication

The handle was made before the hammer head was cast. This was possible because of investment cast fidelity to the original design. The handle was made from a prefab oak table leg from Lowes. We used an old spokeshave to shape the grip of the handle, and a drill press with an endmill to shape the head insert. After the final shape was set, we sanded it with 100 grit sandpaper. The pattern created for the handle was traced onto the wood surface in pencil and then burned into the handle with a wood burner. We decided to use a stippling pattern because it gave a nice texture to the design and added grip to the handle. Finally, we applied a single coat of boiled linseed oil to help preserve the wood and protect it. An originally unintentional effect that we capitalized on was rubbing light amounts of steel dust into the handle to age it and give it an antiqued finish.

Figure 7. Steps to create the handle, including milling, shaping, wood burning, and the final part

The hammer heads were received with a sand-blasted finish. To make the designs stand out, we used a dremel to polish the border and designs to create a shiny surface that contrasts with the dull rough bulk of the hammer. Firstly, the delicate designs were covered with masking tape, and the borders of the designs were ground, sanded, and polished with a dremel tool. After the borders were completed, the masking tape was removed and the designs were carefully ground, sanded, and polished in a similar manner, although with smaller, more precise bits.

Figure 8. Pictures of the hammer head before, during, and after polishing

The foundry unfortunately forgot to cast our pommel, so we went to Ace Hardware and bought a steel pipe square end plug that we ground down into a pommel shape.

Figure 9. The pipe plug before and after shaping and polishing into a pommel

Finally, we friction fit and used JB Weld to attach the pommel. Then we proceeded with our original plan for the head, using more JB Weld and a screw down through the top of the hammer to secure it all in place.

Figure 10. The finished hammer

Problem solving

We initially wanted to cast around a core of ceramic foam. This ceramic core would be lightweight and would survive the casting process. We considered using aluminosilicate foam furnace blocks, but the blocks did not come pre-fired. This meant we would need to machine and fire the blocks ourselves, taking into account the linear shrinkage of 3.5%. We also were in contact with a ceramic foam filtration company but they determined that they could not help us because of the complex part shape and our timeline. Due to these constraints and limited time and resources, we decided that the safest option was to machine oak blocks for the core instead of ceramic. We planned to insert the oak core into the hammer head after casting and then weld the entire head shut.

However, the foundry forgot to machine the oak blocks and welded the bottom of the hammer shut while it was still hollow. In addition, the foundry left the gates on the top of the hammer. Luckily, the gates did not interfere with our art on the top of the hammer, but it did affect the overall weight and balance of the head and final design. Lastly, the rune for protection was not present in the finished hammer. We are unsure if it was sandblasted off after casting or if it was not included in the original mold itself.

Figure 11. Pictures of the bottom with emergency epoxy fill-holes and the top with the gates.

The foundry also forgot to cast our pommel. We were able to form a makeshift pommel out of a steel pipe plug, as described in the fabrication section.

Video Production

Both the testing video and video report were produced using iMovie. The videos are based on clips and images of the hammer as it was developed. Along with these other pictures were used to provide a visual aid to our historical context. Out of an abundance of safety, audio recording was performed in each of our own homes rather than in the recording studios at Texas A&M University. This was made possible using Audacity audio recording and editing software. We were able to capture and present high speed footage of the hammer in action in the testing video using two iPhones capable of shooting at 240 frames per second. To represent that this whole hammer making process was very collaborative we had each team member speak for a portion of the report video so that everyone's contributions were recognized.

Conclusions

Through the process of creating this hammer, we learned indispensable skills in teamwork, the design process, and problem solving. We encountered many unexpected obstacles and setbacks, but we learned how to adapt creatively to find solutions. We all gained a greater appreciation for the time and dedication needed in the steel casting process. Although the restrictions from the pandemic did limit our ability to work in the lab as a team and restricted our access to some of the proper equipment, we were able to communicate efficiently and divide the work evenly. We each had our own area of specialization and worked together on the overall hammer design. This allowed us to delegate tasks effectively while still working as one cohesive unit. Despite the setbacks from the pandemic and various problems along the way, we adapted well and created a hammer that we are all very proud of.

Figure 12. The finished hammer

Special Thanks

On behalf of our team from the MSEN department from Texas A&M, we would like to sincerely thank you for your support and generosity during these past couple of months for the Cast In Steel Competition 2021. Even with all of the setbacks from COVID-19, we were able to build a detailed hammer that we are all very proud of. We value your ongoing support and sponsorship and look forward to possibly working with you in the future for other possible projects. Our department is also aware of all of the effort and assistance that you have given our student project, and they would like to thank you too.

Special thanks to our sponsor:

AMERICAN FOUNDRY GROUP

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