Cast in Steel 2021

Thor’s Hammer Final Report

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Team Members

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Everett Notaro is a junior manufacturing engineering student who worked on the project design and technical report and was a former Officer for the Society of Manufacturing Engineers.

Keven Nieto-Ramirez is a senior manufacturing student. He went on tour along with other team members to the partner foundry and worked on the report and hammer assembly.

Jacob Richards is a junior manufacturing engineering student. He is the Secretary of Society of Manufacturing Engineers and Vice President of American Foundry Society.

Arina Poggioli is a sophomore manufacturing engineering student and is an officer for the Society of Manufacturing Engineers at Cal Poly. She also enjoys working with young robotics teams on her free time.

Abstract

For the 2021 Cast in Steel competition, we were tasked with designing and casting Thor's Hammer. Thor's hammer is relatively well known from movies and pop culture, but Thor's Hammer originates from Norse Mythology. Thor was the god of Thunder lived in and guarded Asgard. Thor's main weapon was his hammer Mjölnir. Mjölnir was more than just a normal weapon as it would return to Thor like a boomerang and was used in numerous formal ceremonies.

Given the competition requirements of 6 pounds and 20 inches, we decided to design a hammer that had clear ties to Norse Mythology while still putting our own unique touch in the design. From the options that our foundry partner the American Casting Company gave us we selected 4340 Steel. The ability of 4340 Steel to withstand repeated stresses and high forces makes it a good choice for our hammer. With American Casting Company's help, our design was 3D printed, coated in ceramic slurry, and burned out to create our two trees that each contained three patterns. After our hammers were cast, they were sent to be hardened. Once the hammers arrived with our team, we mounted them on handles.

Introduction

For the 2021 Cast in Steel competition, we were tasked with creating a functioning Thor's Hammer. The hammer should be no more than six pounds, and a length of twenty inches or less. This is to ensure that the hammer could be used as a one-handed hammer.

Historical Background

Thor's hammer, Mjölnir, is a relic that dates back to the 11th century. It is the weapon of the Norse God, Thor, and has also become a symbol that is still widely known today. Thor was the protector of Asgard and successfully protected them from threats like giants. It was believed that the sound of thunder was the sound of Mjölnir crashing against his opponent's skulls. Mjölnir would return to Thor's hand, much like a boomerang.

Mjölnir was forged by dwarves and had a short handle because Loki, disguised as a fly, bit the eye of the dwarf who was forging the handle. The short handle is a key characteristic of the hammer, as Thor would wield the hammer one-handed as shown below in Figure 1.

Figure 1 Historical Inspiration

Because Thor was the protector of Asgard, his hammer became a symbol of protection rather than destruction. The hammer would be presented at weddings, births, funerals, and other ceremonies. Today, the hammer is worn as an amulet, as a symbol of protection and good fortune. It became a symbol in response to a cross becoming a symbol for Christianity. An example of Thor's Hammer amulet is shown above in Figure 1.

Hammer Design

For our design, we wanted to tie elements of Thor's hammer that come from pop culture and Norse Mythology as well as add our own unique touches. From the Thor's hammer seen in the Marvel Cinematic Universe, we kept the square face with large chamfers that feature a braid. From Norse Mythology, we wanted to limit the hammer to be wielded one-handed. In order to make our design shape unique we opted to use an asymmetrical shape that features a hammer face on one side and a blunt axe.

We also used Nordic Runes and the eight-legged horse to embody the culture of the hammer. The eight-legged horse belonged to Odin and was Loki's son but as the Cal Poly SLO Mustangs, we felt it was ideal to include in our design. The Nordic Runes that we selected reads “Cal Poly” (Top) and “SLO” (both sides). On the sides, we added material relief holes to cut down on the weight of our hammer since the size and material density was already cutting close to the competition restriction of six pounds. Additionally, if we chose to, we sized these holes to test whether or not these holes could be fitted with a roll pin to ensure that the hammer would be secured. However, after a few tests, we decided that the roll pins did not add any more support and actually weakened the handle.

We selected a hickory-wood handle to minimize vibrations, and a shorter length inspired by the history of Mjölnir. The handle of the hammer was placed near the center of the hammer head because we wanted to have a symmetric appeal between the front face and the blunted axe, while the actual center of gravity for the hammer was towards the face of the hammer. Our team sought to make a hammer similar to the following image because we wanted to distinguish ourselves by using the less common, asymmetric design. Additionally, we decided not to sharpen the axe of the hammer for safety purposes, but the axe still functions well through brute force, as shown in our test video.

Figure 2 Basis of Our Design

SolidWorks Modeling

Using SolidWorks, we had each member of our team research Thor’s hammer and Norse Mythology to design their own version of Thor’s hammer. From there we met and discussed which aspects of Norse Mythology we thought would be important to include in our hammer while still finding a way to make the hammer unique. Some of our initial designs are shown in figure 3.

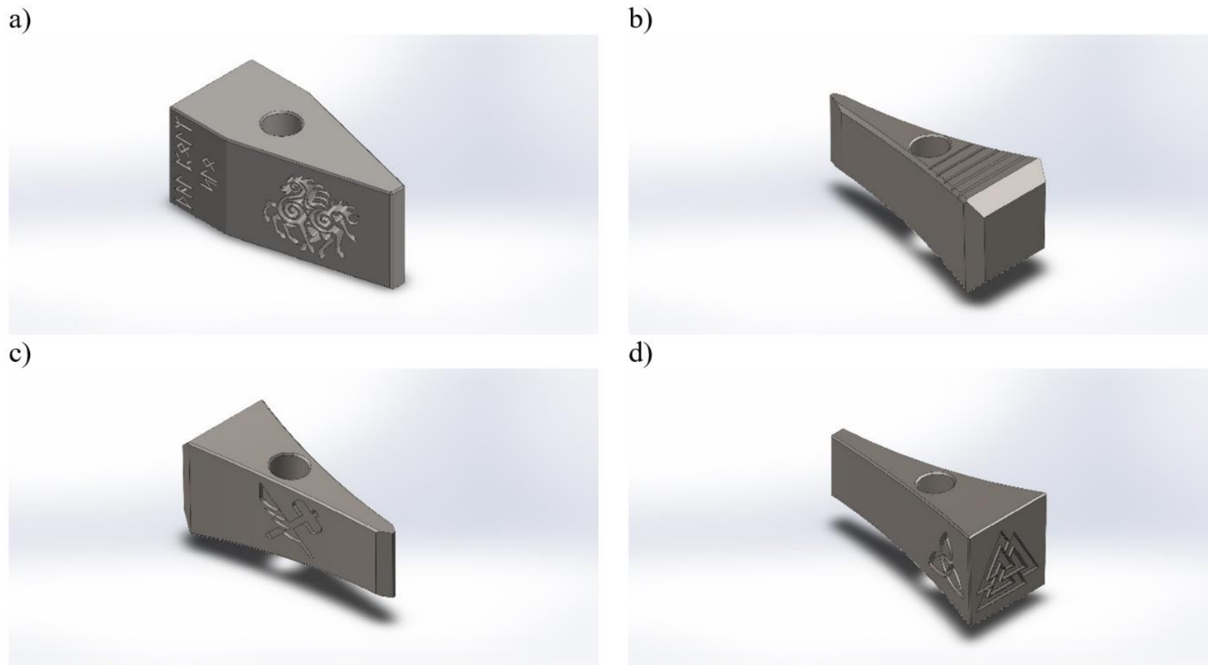

Figure 3 Isometric view of our preliminary hammer designs. (a) Six-legged horse and Norse text: Used in final design (b) Hammer shape: Used in final design (c) Cal Poly crest: Not used in final design (d) Norse Symbols: Not used in final design

What we decided on shown in Figure 5. It is a uniquely shaped hammer that bring together elements from Thor's hammer seen in movies and Norse Mythology while still being able to incorporate elements of Cal Poly San Luis Obispo. Our final design incorporated parts from every person's unique design, and it was focused on showing the level of detail that investment casting could achieve.

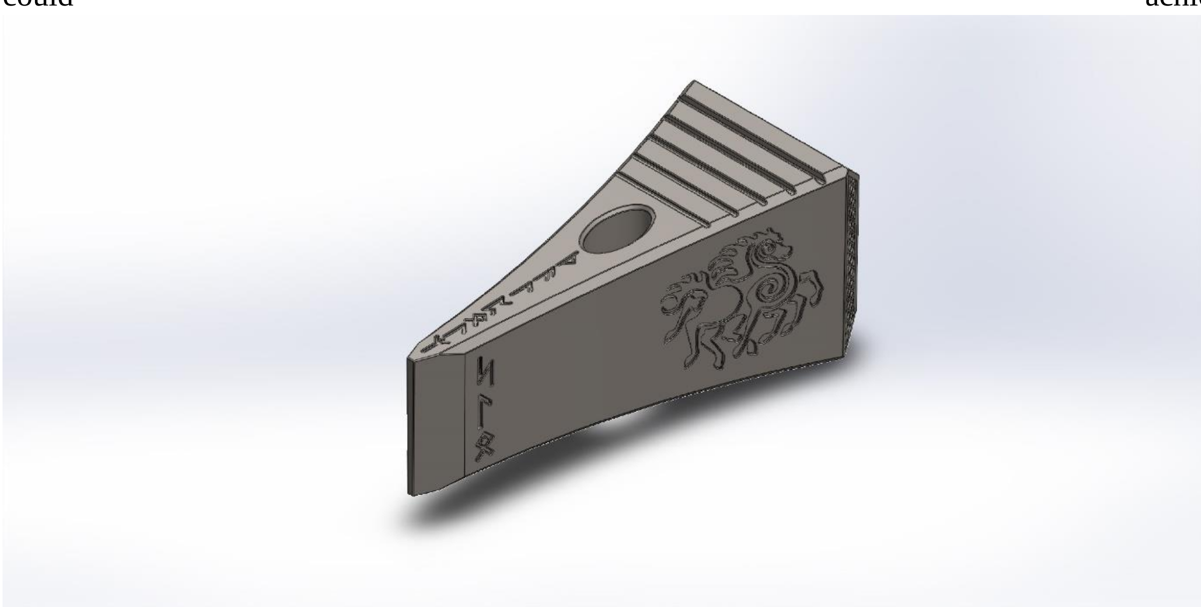

Figure 4 Isometric View of Final Thor's Hammer Design

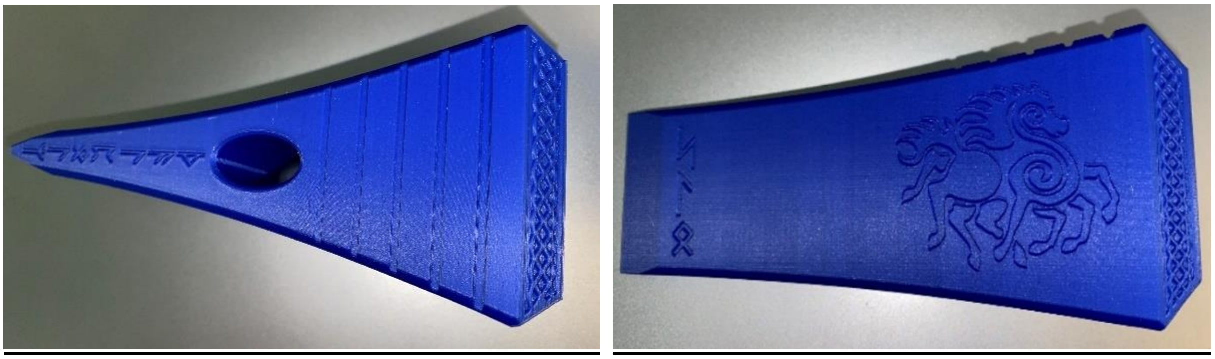

Figure 5 3D Printed Model of Hammer Head

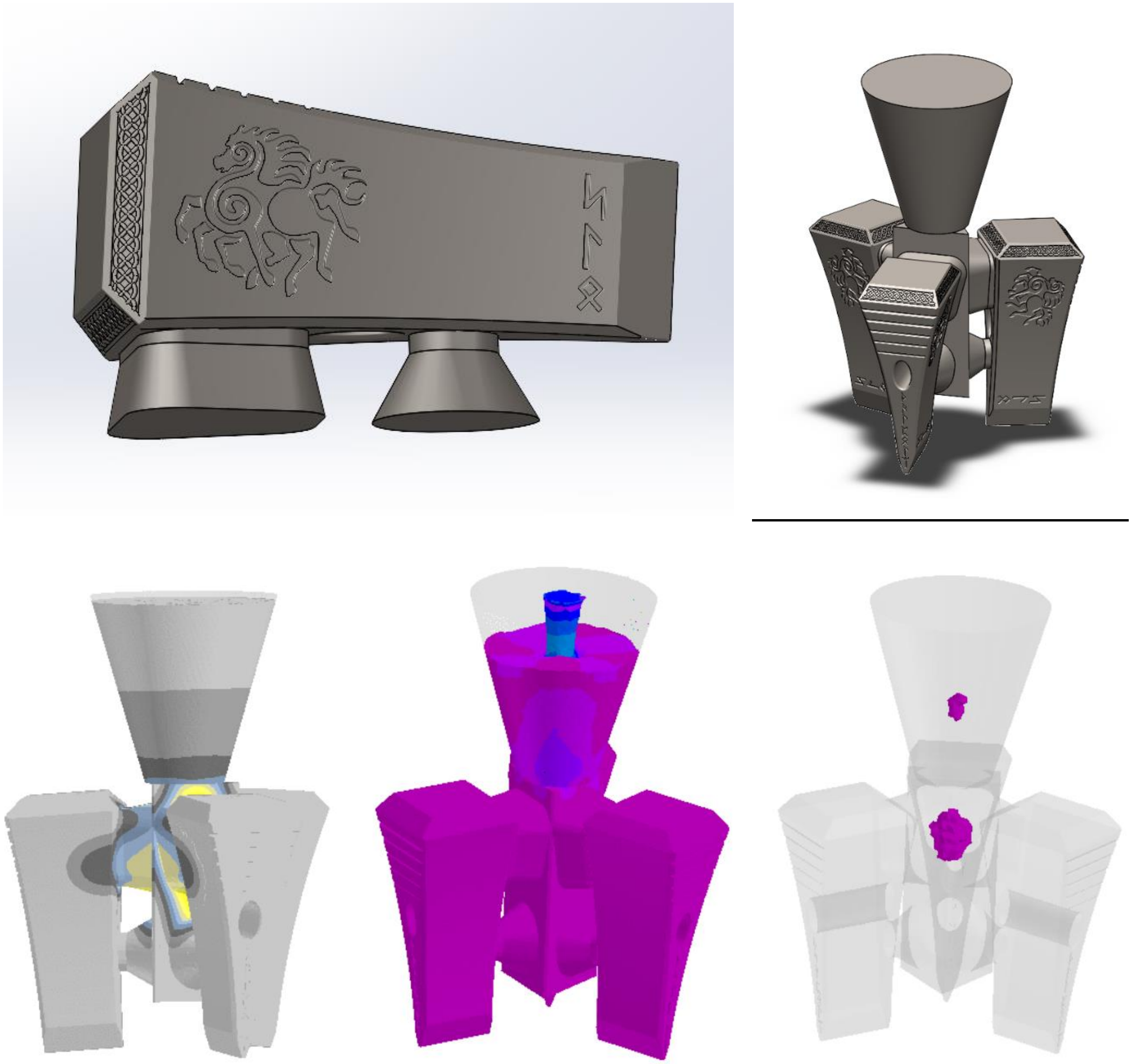

Figure 6 Gating Analysis

Preliminary Plan

Week 3: Final gating/simulation design completed (January 22nd)

Week 7: Casting Day (Feb 15th); Casting Completed (Feb 19th)

Week 10: Team Test Video (March 12th)

Finals Week: Post processing completed, and hammer mailed (March 15th)

Finals Week: Report, Hammer, and Video Due (March 20th)

Material Selection

We chose to use 4340 steel over 17-4 or 15-5 because this low alloy steel is known for its toughness and strength. American Casting Company was able to provide us 17-4, 15-5, or 4340 steel, so our team was able to research the properties of each material before selecting our choice.

First, when inspecting mechanical properties, all the materials showed a similar yield strength of an average of 1000 MPa, according to the condition of the material. Therefore, we looked further into the maximum hardness properties of the materials, and they all displayed a similar maximum Rockwell C hardness of around 45.

When diving further into research, since 17-4 and 15-5 were both stainless steels, they are reputable steels for hardness, but lacked the toughness that our team was seeking for our material. Since the hammer was going to be subjected to heavy blows, we sought a steel that would be better over longer impacts without any potential points of fracture, especially near the handle. 4340 was shown to have great shock and impact resistance along with wear resistance once it was hardened. Also, the material was described to be great for a hardening process afterwards, and the ability to work with this steel was said to be excellent for several methods of manufacturing.

Process Selection

Several criteria were looked at to choose what process to use. Investment casting provided the best dimensional tolerance for the small details such as the runes and horse engraving. The ceramic gating design that was used was produced from 3D printed investment casting wax molds, as shown in the following photos, to ensuring a smooth finish and an even filling process. Additionally, the size and shape of the hammer is best suited for investment casting as a typical investment casted part is small in scale and has a tolerance within .005, as shown below in figure 7.

Figure 7 3D Printed Investment Casting Wax Mold

When looking at surface finish, the investment casting process also offered a common finish of between 63 to 125 µin with better finishes possible. Die casting could have offered better potential for a finish, but since the part was sand blasted following the casting, our finish was not too important in this project.

Figure 8 Surface Finish on Final Part

Figure 9 Investment Casting Process

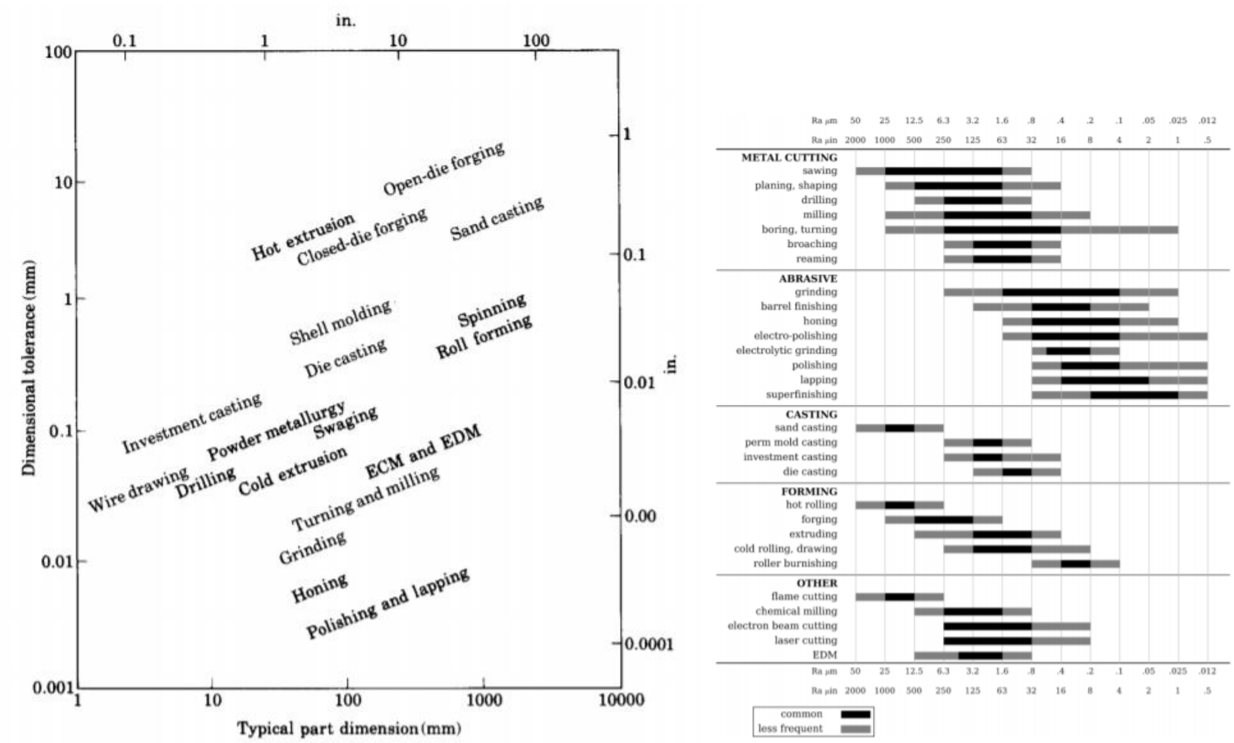

Figure 10 Process Selection

Sand Casting would not work because it is meant for low temperature melting materials and a rough surface finish. Wax injection was had too high of a cost. Lost foam is meant for high production volumes instead of low production.

<u>Heat Treating</u>

Our team inspected the methods for annealing, normalizing, hardening, aging, stress relieving, tempering, and carburization when heat treating steel. Overall, we decided that tempering then normalization would allow our hammer to achieve the correct hardness and toughness levels for our project.

~~Regardless of method chosen, the basic steps include heating the metal to a specific temperature, holding it there (aka soaking), and then cooling the metal back down~~ (American Machine Tools Co., N.D.)~~. Because heat-treating manipulates the microstructure of the material, all these methods produce different structural and physical properties in the final material. This can include changes to its strength, toughness, brittleness, electrical resistance, and more~~ (Velling, 2020) ~~. Given our use of a ferrous metal, our scope of heat-treating processes was narrowed down to methods such as hardening, annealing, normalizing.~~

Ultimately, normalizing was selected because it produces a desirable toughness/hardness ratio and leads to a stronger material in a balanced proportion. (Velling, 2020). Normalizing produces a uniform grain size and composition in comparison to other heat-treating methods. (Velling, 2020). Given the designation of our tool as a striking tool, it was crucial that these properties remained balanced while maximizing toughness. Normalizing is done to parts which will require impact strength as our hammer will encounter. Our team chose to aim for an HRC of around 50-55 because we were able to initially test the harness of a few hammers on campus, and we found that larger wielded hammers fell within this range. The following photo shows these tests that we performed with the Wilson Rockwell hardness tester.

Figure 11 Rockwell Hardness Test of Other Hammers

To achieve normalizing, the metal must be heated beyond its upper transformation point (or ACM line) into the austenite range, then held at this temperature until the structure is fully converted in austenite. (Unknown, N.D.). Our hammer was tempered and after quenching, reheated to a normalization temperature. In the case of 4340 steel, this typically calls for a temperature of around 850C to 945 C. (Unknown, GENERAL CHARACTERISTICS OF ALLOY STEEL 4340, N.D.). Our normalizing occurred at a temperature of 850 C due to these characteristics and was air cooled.

Assembly

Our hammer assembly was created by mating a store-bought handle to the created hammer. First, the store-bought handle was chopped to the desired length and rounded to account for the curvature of the sides. Next, the handle was sanded to the correct shape of the hole in the hammer and stained. Then, the hammer was engraved by wood burning a design into the sides.

Figure 12 Final Hammer Assembly

Afterwards, the handle was mated to the hammer head by using the force of the head to drive the wooden handle in with gravity. Finally, the metal wedge was pressed into the top of the handle to expand the outsides of the handle to receive a tighter fit. The following two photos show our first two trials when mating our hammer to the handle.

Figure 13 Initial Hammer Assemblies

Without any previous experience with creating tools, our team initially tried to sand down the handle to mate with the hammer, but with more research, the following iterations of our hammer used the weight of the hammer head to drive itself onto the handle with minimal sanding or adjustment needed. This process allowed our hammer to receive a tighter fit within the assembly, attempting to minimize dangers with the head slipping of the handle. Our team also tried drilling holes into the side of the hammer through the weight-relief holes. We pressed in two roll pins afterwards and tested the hammer with heavy blows to concrete, but the roll pins severely weakened the hammer handle. Within ten minutes, our hammer head snapped off right at the base, as shown below in Figure 15, and our team concluded that we would omit roll pins from our final hammer assembly.

Figure 14 Effect of Roll Pins Weakening Handle

Video Production

For the video showcasing the hammer worthiness we met outside at an empty parking lot following proper covid safety guidelines. We took a video smashing several objects with the hammer such as various fruits, a pinecone, a pencil, and splitting a branch. We sought to display both the hammer side and the blunted axe to show the versatility of our project.

The final video is a presentation for the project, highlighting key processes with pictures.

Conclusions

Our team's goal was to create a Thor's Hammer that weighed no more than 6 pounds with a length no more than 16 inches. Our final design included engraved surfaces to show the details of investment casting, along with an asymmetric face for uniqueness and weight distribution. Our hammer has a handle length that encourages it to be wielded one-handed and designs that were inspired by both the MCU and the historical origins of Thor's hammer Mjölnir. Upon completion, our hammer weighed 6.0 pounds and well below the length constraint.

Throughout the process, we were able to gain valuable skills within the manufacturing casting industry, and all of us expanded on our abilities to operate as a team virtually. Although each of us contained our strengths before the project, we were all able to contribute to the final product and pick up new talents that will last throughout our careers as manufacturing engineers.

Acknowledgements

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