Cast in Steel 2021 Thor's Hammer Competition

Pittsburg State University

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And

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Participants

Manufacturing Engineering Technology students Colton Southwell, Austin Jacks, and Kolton Darrow were joined by Mechanical Engineering Technology student Jacob Tiehen to compete in the SFSA Cast-in-Steel competition of 2021 under advisement of Professor Dr. Russel Rosmait representing Pittsburg State University.

The Design and choosing a process

The design of this hammer was largely inspired by the Marvel Avengers style of Thor's hammer. Using Solidworks, the first step was to try and re-create the original design. This gave us a blank template to model from. After simulating the original design, the head of the hammer alone would weigh approximately 11-lbs in cast alloy steel.

Right away we realized our primary concern was weight reduction. Many different concepts were considered including design alteration, a hollow core, and a split metal construction. We needed a design that would reduce the weight dramatically while still maintaining its integrity. Using Solidworks simulations to locate the forces acting on the hammer we found that most of the force acts on the face of the hammer and fades towards the center of the handle. This study led to the decision to taper the inside of the head back to the center of the handle, matching the forces displayed on the simulation in a conical shape. The frame from the original design was kept for both support and aesthetic reasons. After the weight problem was fixed, we could move on to other aesthetic additions to the hammer. A Nordic design was chosen to frame the hammer faces (see figure 2), as well as a Nordic font style to emboss *Pitt State* on one side, and the SFSA logo on the opposite side. The design of the head was then ready for casting simulations.

This head alone was still over 5-lbs and needed a handle that could support its weight while still feeling balanced in use. The handle was about 15 inches long and constructed in oak. It is indexed to easily hold and locate the faces of the hammer. The spiral on the hammer acts as an aid in gripping the hammer and represents the rings on the original Marvel Avengers handle design. We want to thank Samuel Galliart from World Class Prototypes for assisting in handle design as well as donating time, material, and CNC run-time to provide us with two oak handles.

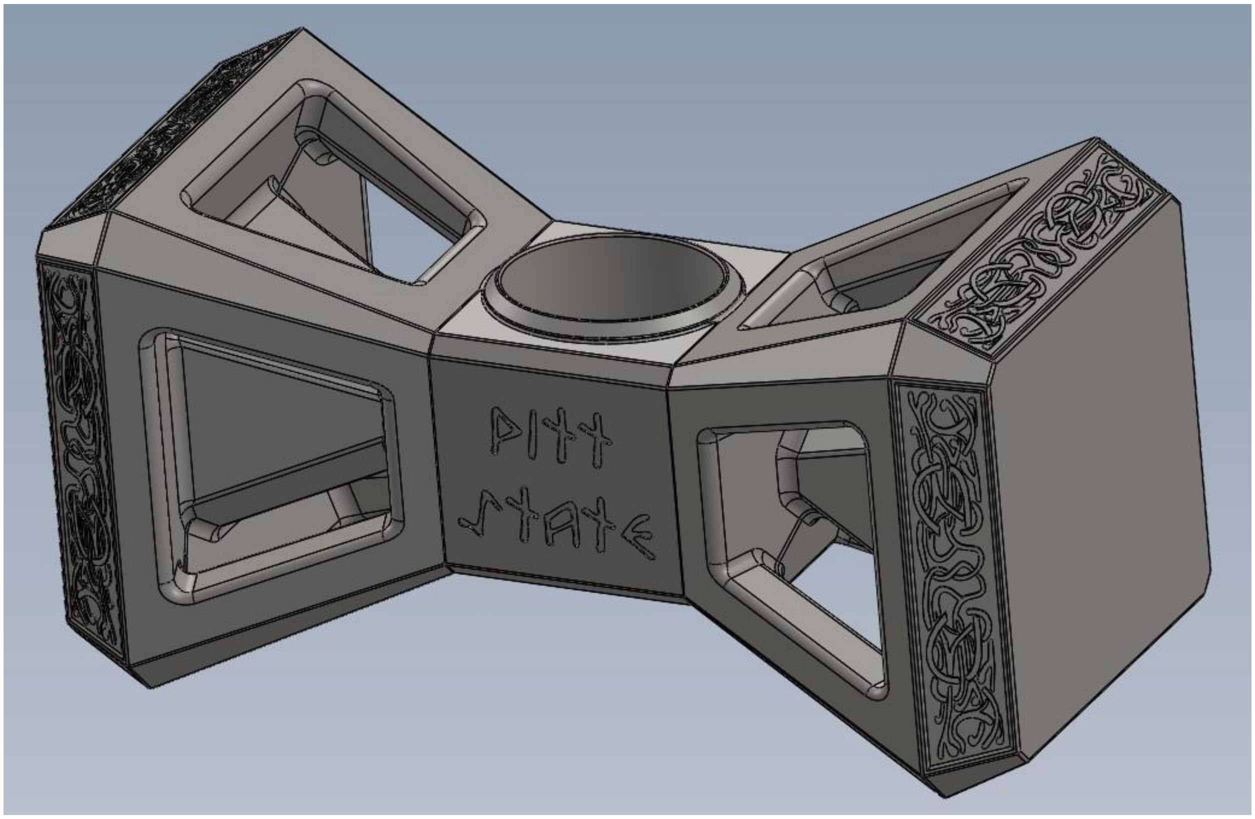


Figure 1

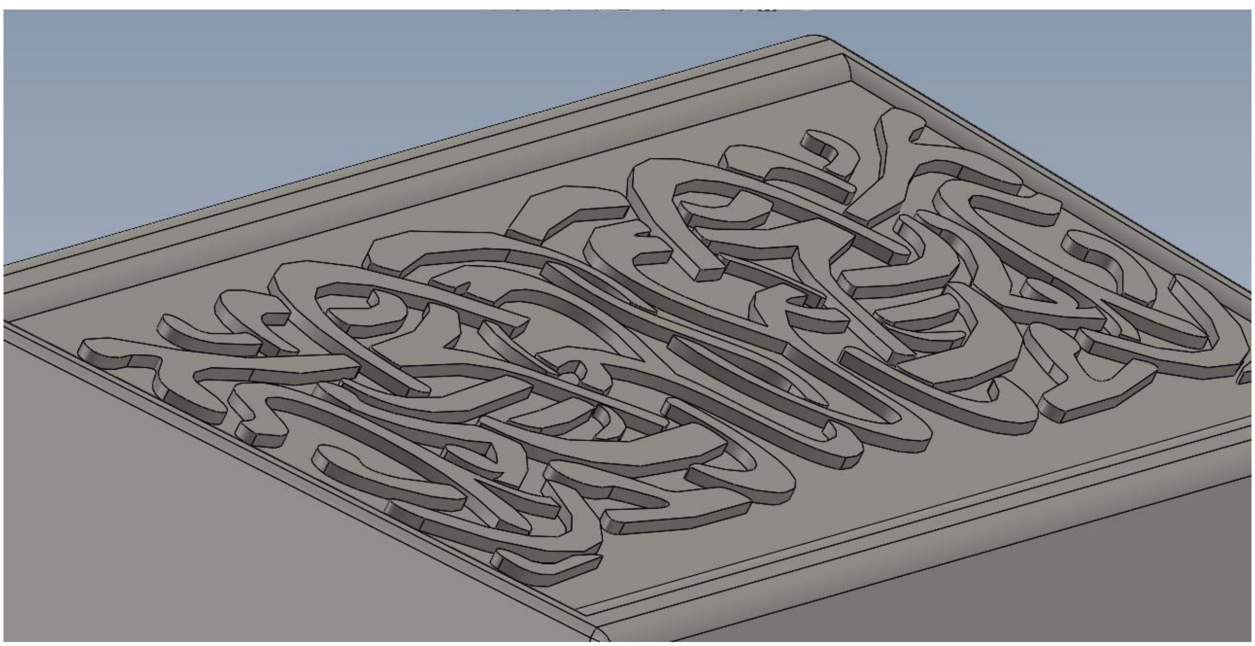


Figure 2

Alloy Selection

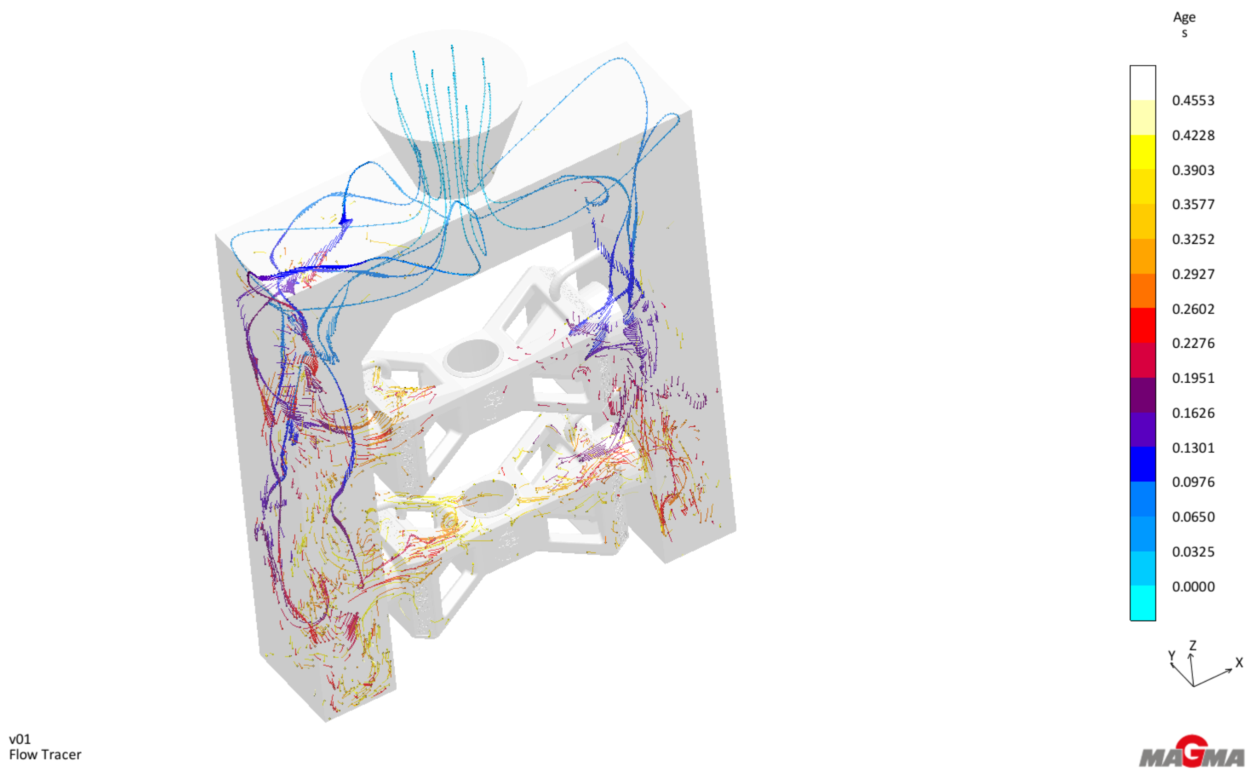
After discussion with our partner foundry Monett Metals, we chose to utilize investment cast steel alloy AISI 4140 as we decided it should be suitable after heat treatment for use as a hammer head. Monett Metals was also preparing to pour a batch of anvils made from the same alloy so it was convenient to integrate our casting in the production process without too much disruption of the foundry's production schedule.

Alloy Type	Condition	Tensile Strength		0.2% Yield Strength		% Elongation Range	Hardness Range or Max
		English KSI	Metric MPa	English KSI	Metric MPa	(2.5 cm or 1")	
4140 Investment Cast	Annealed Hardened	- 130 - 200	- 896 - 1394	- 100 - 155	- 690 - 1069	- 5 - 20	100 Rb 29 - 57 Rc

Figure 3

Simulation

Once the team was satisfied with the design of the hammer, we chose to move forward with casting simulations to determine the feasibility of our castings. With help from Monett Metals, we created the following gating system (seen in figures 4-8). Looking at figure 4 we can see a snap shot of the flow tracers to determine which cavities of our mold will begin to fill first. Viewing the velocity plots in figures 7 and 8 we began to be concerned with turbulence in the steel in the lowest most hammer. While the gating does not seem to create undesirable characteristics, we noticed that the geometry of our hammer head creates a venturi or nozzle effect where velocity of the steel increases substantially as the center of the hammer begins to fill. The team determined that the lowest most hammer head may yield undesirable features due to turbulence in the steel. Since we will have 3 full trees we were determined a re-design of gating or the hammer was not needed as we only need to yield one good hammer, this will be further supported with looking at the next components in this simulation. In figure 6 we looked the fraction of liquid during the time step t=25s. We were concerned with being able to feed the heavy sections near the face of the hammer as the gating solidifies before the entire hammer has solidified. Looking at cross-sections of this same study at multiple time steps we determined the gating continues to feed only near the very center of the gate. With some uncertainty we turned to using other powerful features in the MAGMA software to determine if we will see void due to shrinkage or porosity. The results from those studies determined all areas of conflict were beyond the hammer, in other sections of the casting tree and sprue. The team determined we were now ready to move forward with the manufacturing process.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0.3577
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0.2927
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0.2276
0.1951
0.1626
0.1301
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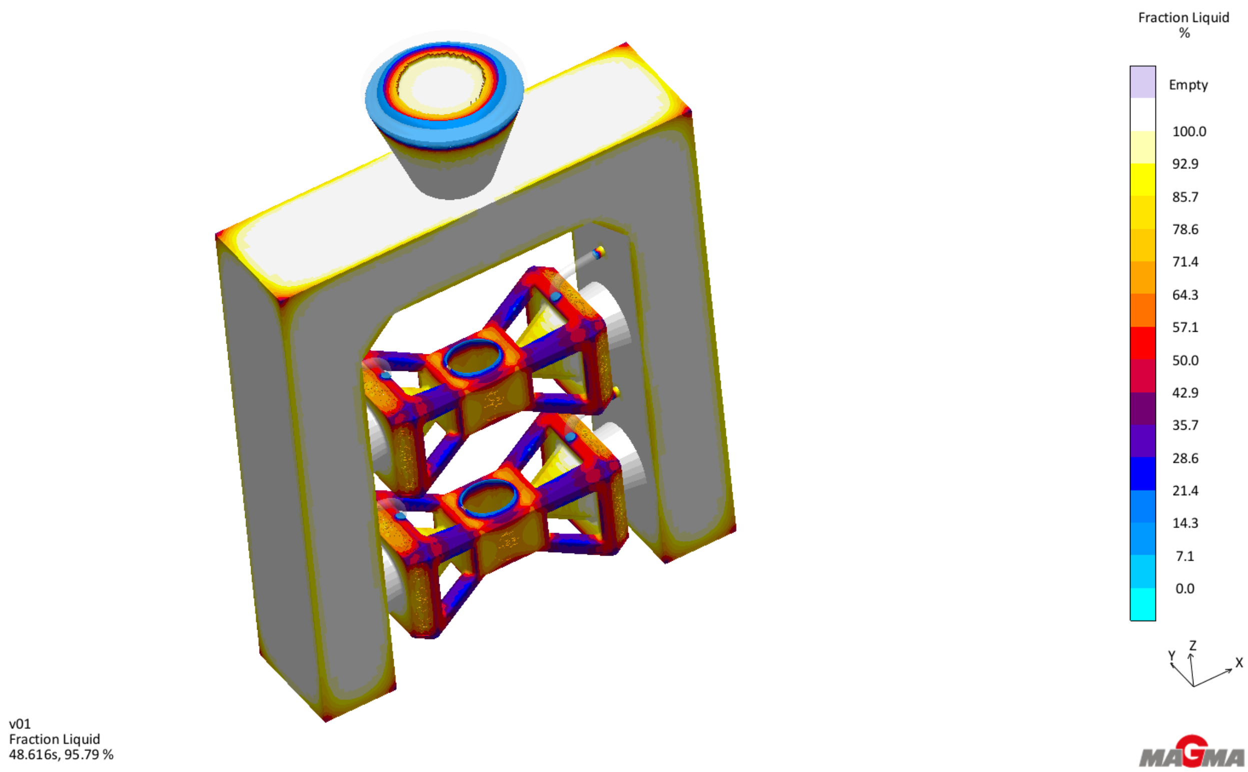
0.0650
0.0325
0.0000
Y
Z
X
v01
Flow Tracer
MAGMA

Figure 4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%
Empty
100.0
92.9
85.7
78.6
71.4
64.3
57.1
50.0
42.9
35.7
28.6
21.4
14.3
7.1
0.0
Y
Z
X
v01
Fraction Liquid
48.616s, 95.79 %
MAGMA

Figure 5

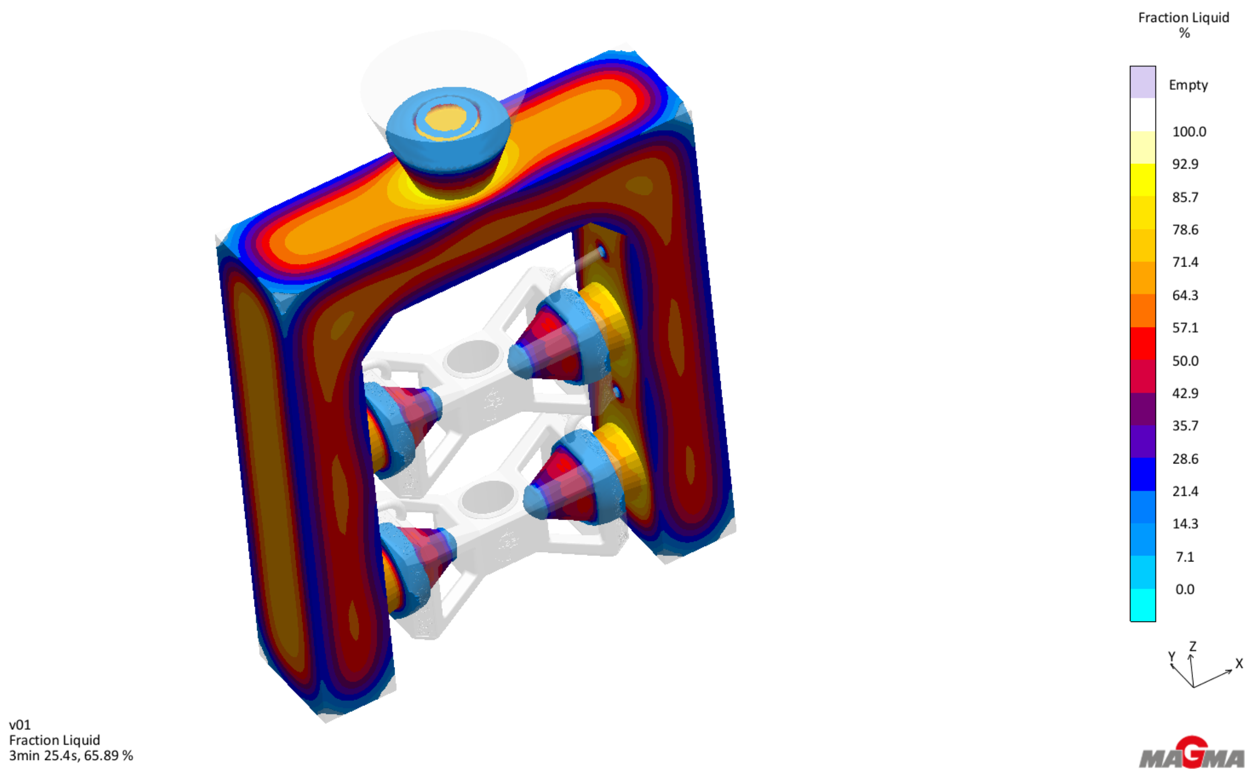

Figure 6

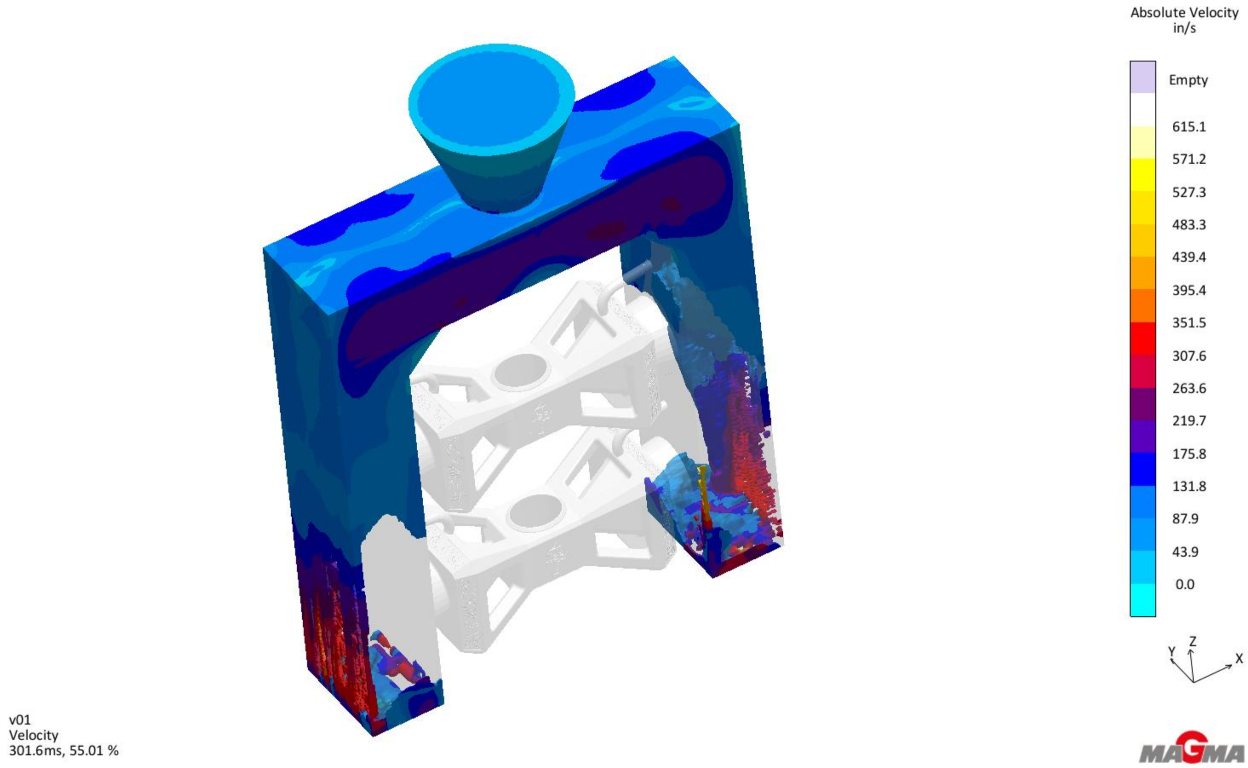

Figure 7

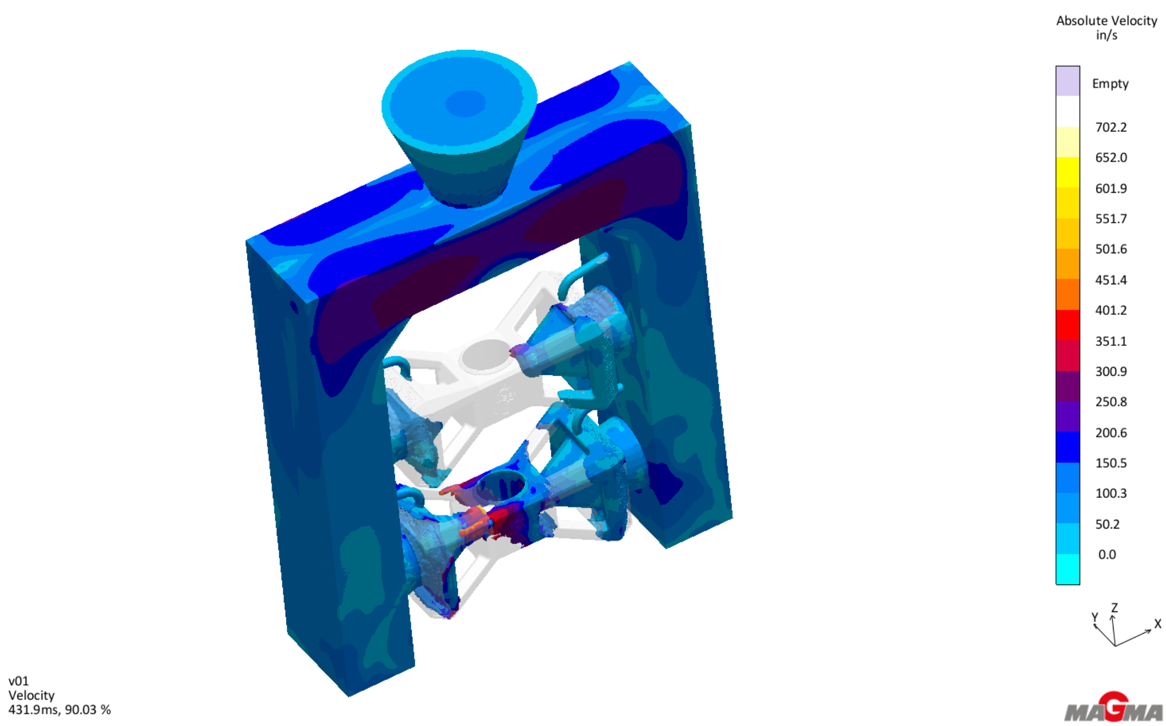

Figure 8

<u>The manufacturing processes</u>

Pattern making

When using the investment casting process, it is ideal to have a wax pattern to form your shell for its properties that allow high detail transfer, dimensional accuracy, and high-quality surface finish. It would have been possible to create wax injection forms in a multi-piece design that would have allowed us to create our pattern in wax. The complexity of creating a wax pattern for this geometry however, would have been very difficult and time consuming, although not impossible. Due to the geometry we decided to us PLA (polylactic acid) patterns created with an FDM (fused deposition modeling) rapid prototyping 3D printer. Using this “lost PLA” investment casting would allow us to attain a near net casting with exception of surface finishing and gate removal. See figures 9 and 10 showing .STL files in the slicing software Cura in both normal view and view as sliced which includes the structure seen in blue/green which is support structure. See figures 11 and 12 for a snapshot of the printing process and the result(s). It should be noted that we wanted to minimize casting defects and environmental impact so we opted for a shell thickness of 2 layers throughout, with a infill volume of 8%.

Normally we would account for printer scaling issues and shrinkage of the casting. We opted to print our models without this allowance to attain a slightly smaller product with a higher likelihood of fitting under the weight requirement.

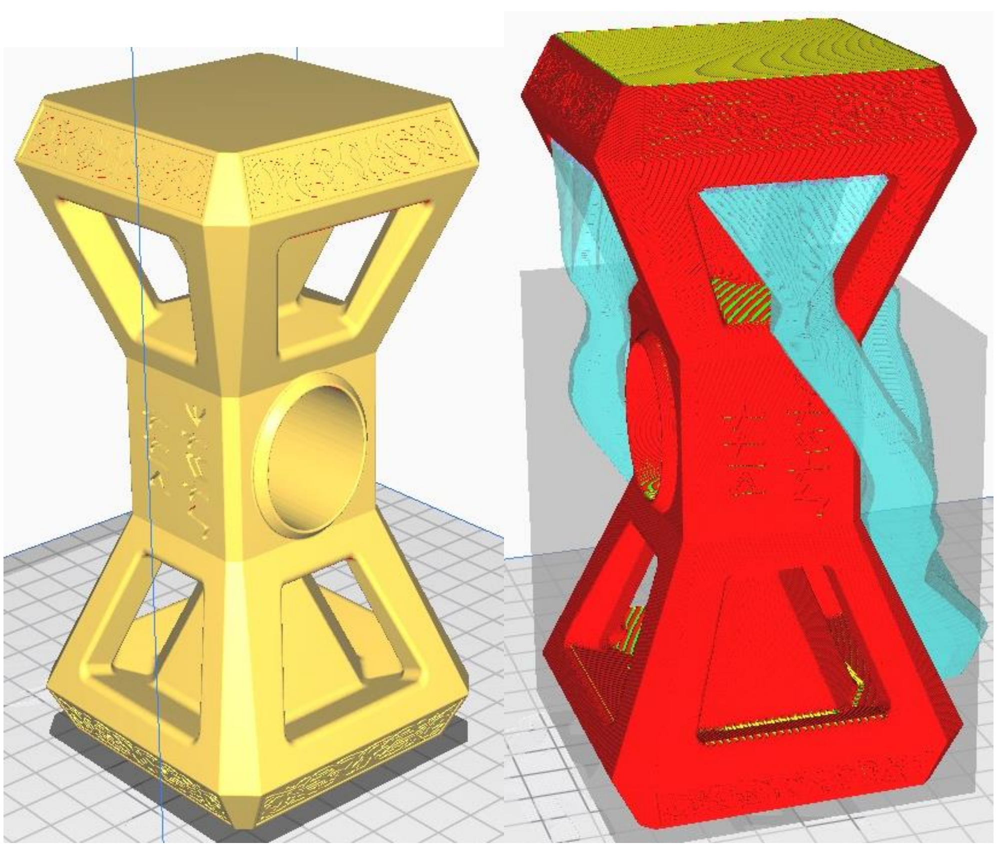

Figure 9 and 10

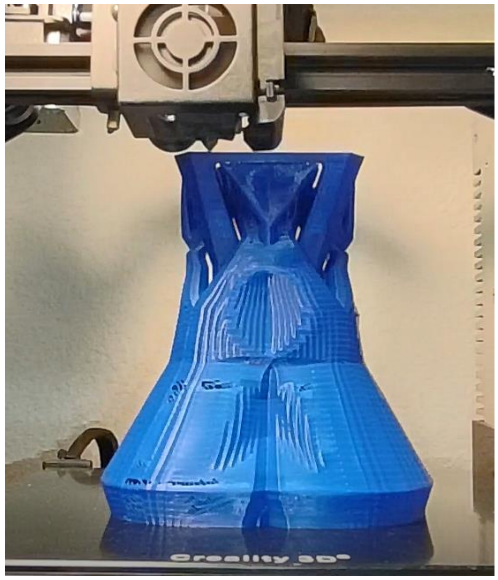

Figure 11

Figure 12

After our design was cleared for production the hard-working team at Monett Metals got to work creating our investment tree. The PLA patterns were glued to a traditional wax sprue. The prime and back-up coats were applied using their standard practices. After melting out the wax and PLA in the autoclave the remaining PLA was burned out in the pre-heat furnace while also brining the shell up to pouring temperature. After this our hammers were cast, knocked out after cooling, cut-off the tree at the gate section and promptly sent to Trojan Heat Treat.

Heat treatment

With help from Trojan Heat Treat in Joplin MO we were able to harden our casting to be within an acceptable range for a hammer head in terms of tensile strength, yield strength, and hardness while still retaining some level of toughness. The heads were heated to 1550*F and the quenched in a turbulent bath of oil. Figure 13 shows the best of the 6 hammers that we will use for our final product.

We expected a Rockwell harness close to 55 Rockwell. After some metallurgical testing at Pittsburg State University, (see figure 14) we found the head to be 41 Rockwell, which is closer to a tempered hardness when tempering at 800*F than a hardened hardness although we had no time to address this with a limited timeline.

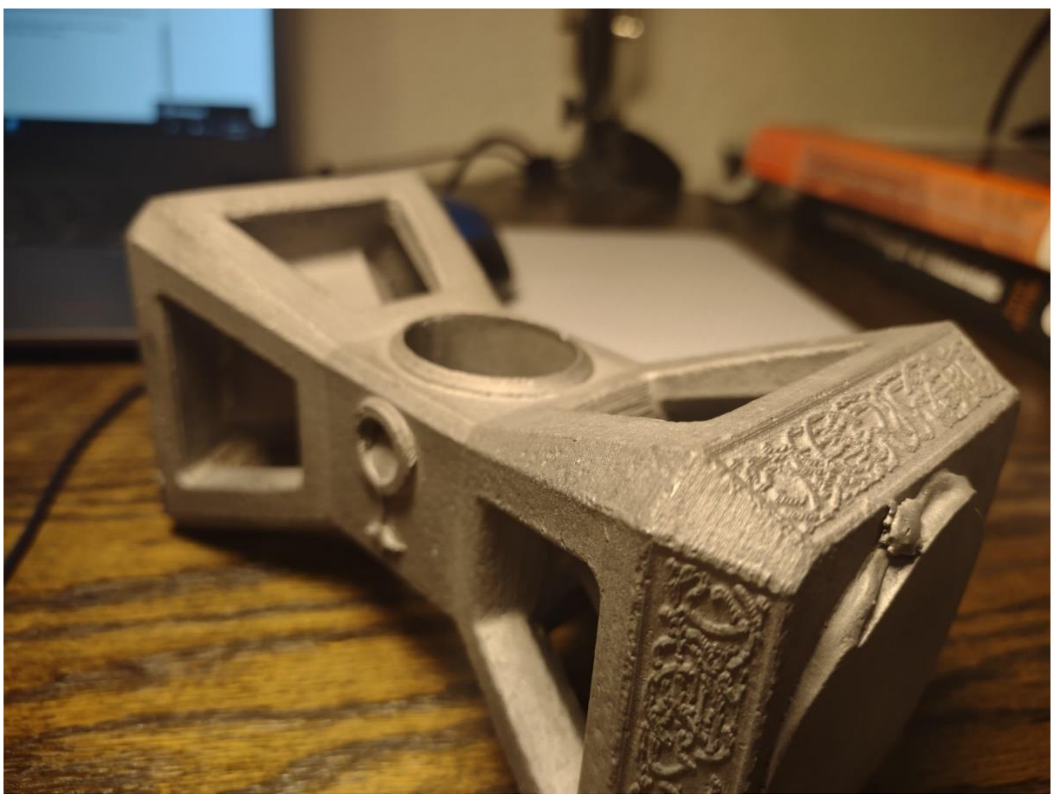

Figure 13

Figure 14

<u>Post processing</u>

The hardness of the hammer resulted in very difficult subtractive manufacturing processes and finish work. Thankfully we did not have an excessive amount of finish work to do. We course sanding belts in the 60-grit range to remove what remained of our gates. Progression was made to finer sanding belts to attain a smoother finish on the hammer faces. Wet sanding equipment was used to attain a near polish finish after this. We used a Dremel with various grinding and polishing bits to finish all other surfaces besides the hammer faces.

Figure 15

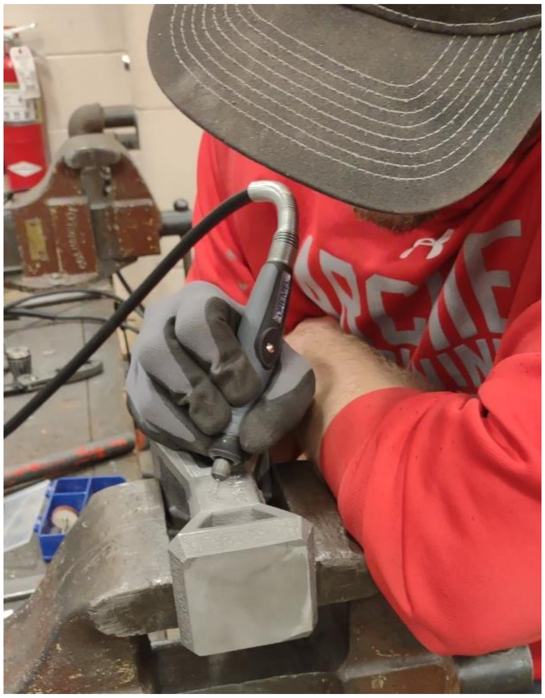

Figure 16

Figure 17

The team decided we would use a passivation process called “cold bluing” to the surface of the hammer to prevent oxidization and rust while also achieving a darker look that we desired. Other alloys would have prevented the need for this although the hardened cast 4140 easily oxidized with the presence of moisture to an extent that would be unacceptable for a finished product. This dark look would also allow use to remove the “blued” surface in sections like the raised Celtic knot boss features framing the faces of the hammer for a contrast as well as portions of the SFSA logo.

Figure 18

Fitting the handle

As mentioned earlier, another advantage to purposely not accounting for shrinkage allowance in our 3D-printed patterns is that the handle can be sanded down on the mating faces for a tighter fit when designed to fit our modeled hammer geometry. We sanded down the mating faces as seen in figure 19 followed by hand sanding for a more precise fit. The handle was designed with an extended connection section to allow full seating on the taper portion of the handle with ample room to cut-off the excess. We used a band-saw to cut the groove for our wedge.

Oak is relatively hard wood for use with a handle, due to this we opted to us an aluminum wedge instead a wood wedge, as any wood wedge would have been softer than the handle and subsequently fail upon insertion. In figure 21 you can see where we are grinding our own wedge from a 6061-aluminum bar extrusion. The other reason we opted to use an aluminum wedge over steel, for example, is due to our concern with weight as we knew we were very close to the limit before this. In figure 22 we seat the wedge. After this the excess wood and wedge were cut with the band saw and filed to a flush seat with the top of our hammer.

Figure 19

Figure 20

Figure 21

Figure 22

Finishing the wood

One of the two handles received from Sam Galliart from World Class Protypes was already sanded to a smooth finish. We opted to use the sanded handle as it looked better than the non-sanded variant while remaining course enough to maintain a good grip. The team wanted to keep a natural wood feel but also attain a finished look to the handle. For this we decided danish oil would be the ideal finish, as we could attain a darker color, and protect the wood without covering the wood with a finish like polyurethane.

Final rendition of the Pittsburg State University Thors Hammer SFSA Cast in Steel entry.


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Acknowledgements

Thank you to everyone at Monett Metals

The engineers, management, and technicians as Monett Metals helped tremendously with designing the gating, creating the investment tree, investment coatings, and following casting processes.

Thank you, Samuel Galliart at World Class Prototypes, for handle design and manufacturing.

Thank You Dave and Doug at Trojan Heat Treat.

Thank you, Professor Rosmait, for your advice and wisdom.

Thank you, Pittsburg State University for providing us the space and resources to compete in academic competitions like Cast in Steel.

Thank you, Steel Founders Society of America, for creating and organizing this competition.

This work was possible because of:

MAGMA

SOLIDWORKS

Ultimaker Cura

FUTURE-TECH

CREALITY