

SFSA Cast In Steel 2026 – Horseman’s Axe

Technical Report

The Ohio State University – Carmen Cavalry



Team Members:

Nicole Appel, Will Vititoe, Alyssa Hlavacs, Suki Reynolds, Mather Graham, Laura Do, Samuel Cosentino

Advisors:

Dr. Alan Luo

Dr. Jason Walker

Foundry Partner:

Fisher Cast Steel, Inc. (West Jefferson, Ohio)

Introduction

According to the Cast In Steel project guidelines, “SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available” [1]. According to the American Foundry Society, casting has been used for over 5000 years, and continues to be used today for most highly engineered durable goods [2]. Casting is responsible for complex metal parts with special applications in modern industry as well as everyday life; the world would certainly look very different without it. Learning about the metal casting process, from traditional techniques to modern tools, is extremely useful for anyone seeking a career in metallurgy or manufacturing, or those who are simply passionate about the subject. Cast In Steel has provided our student chapter with many exciting opportunities to *learn by doing*. This year, we’ve been tasked with the design and creation of a medieval horseman’s axe from scratch.

Historical Background

Robert the Bruce was the king of Scotland from 1306 to 1329 during the Wars of Scottish Independence from English rule [3]. In one of his most well-known battles, the Battle of Bannockburn, Robert the Bruce used his signature horseman’s axe to slay Henry de Bohun, an English knight, killing him with one blow to the head while also shattering his axe handle (much to Robert the Bruce’s lament) [4]. This year’s Cast In Steel project is inspired by this tale of Robert the Bruce and his axe.

A horseman’s axe is a lightweight weapon intended for one-handed wielding that began to see use by heavily armored cavalries in Europe as early as the 14th century [5]. Due to its one-handed nature, the horseman’s axe needed to be light enough for quick and easy wielding while being sturdy enough to deliver powerful blows capable of splitting plate armor. Historically, the handle of the axe could either be made of wood or metal, with wooden handles allowing for larger axe heads [6] [7]. Additionally, most horsemen’s axes had crescent-like blades of varying lengths, proximity of the blade to the handle, and style. Longer, curved blades were effective against plate armor, while shorter, flatter blades were less susceptible to getting caught within the links of chainmail. Wider blades were also typically located closer to the handle (possibly to avoid getting caught on armor), while shorter blades were farther away [8].

Beyond the blade, horseman’s axes also varied in their secondary weapon features. Some axes had spikes opposite to their blade for piercing armor, while others had hammers for blunt crushing force. Some axes had additional spikes at the top of the weapon to be used for thrusts, though this could get in the way of swinging and could lead to the weapon getting stuck [6]. Features such as distal tapers and fullering were used to lessen the amount of material in the spike and reduce contact as the spike passed through armor, and some spikes were slightly curved to match the arc of a swinging strike. Additional features included langets for securing metal axe heads to wooden handles and occasionally a belt hook [8].

Many historical horsemen's axes had a butt plate or swell near the end of the handle to prevent slipping from the user's hands upon swinging. Some had additional guards at the top of the handle and a bit of a longer grip area to accommodate a gauntlet [8]. Decoration on the horseman's axe varied depending on purpose (ceremonial or practical) and could be extremely decorative with engravings and unique toppers, or very simple with no additional decoration [6] [7].

Initial Design Process

The Carmen Cavalry began the design process by drawing an initial visual [Fig. A.1] of the axe. The objective was to determine which attributes would appeal to historical accuracy, while also applying artistic freedom so the design would stand out visually. For the initial design, the team determined the axe would include features such as a pick opposite the axe blade, sheet-metal langets, a pin passing through the eye to hold the head in place, and a solid metal hexagonal shaft with a wrapped leather handle. To accommodate the Cast in Steel length and weight requirements, the team also estimated the appropriate dimensions of each component of the axe [Fig A.2]. Based on the determined size and features, the team developed an initial 3D model of the design in Autodesk® Inventor® [Fig. A.3]. A simple stress simulation was also done on the design to identify potential failure points [Fig. A.4].

The pin connecting the metal handle to the axe head was identified as a potential failure point from the simulation. Additional concerns about the weight of the handle, possible casting defects, and effective head joining methods led the team to decide on a wooden handle instead. This decision appeals to historical authenticity, since many earlier horsemen's axes used lighter, wooden handles to allow for a larger axe head [1]. These handles could also be easily replaced in battle [5]. For this new wooden handle, it was decided that the axe would be secured with a traditional hanging method.

For axe hanging, a handle is shaped to fit the eye of the axe head, inserted into the eye, tapped upside-down from the bottom to force the axe head down the handle, and then secured into place with a wooden wedge [9]. This new handle also removed the need for a leather wrapping, sticking to historically accurate examples of wooden horsemen's axes, such as Robert the Bruce's axe. As the project progressed, langets were also removed from the design due to concerns about the weight limit and added complications to the design process. 3D models of both the axe head [Fig. A.5] and the entire axe [Fig. A.6] were developed based on these new considerations.

Materials selection was performed with practical simplicity and previous competition experience in mind. The team had a goal of selecting a steel with demonstrable castability that could fulfill the mechanical property requirements of the blade and the spike in one casting, without the need for local hardening procedures. Due to the presence of an industry sponsor for this project, material cost was not a factor in the selection process.

For the axe head material, a precipitation hardening grade of stainless steel known commercially as ARMCO® 15-5PH® (15-5) was selected. 15-5 is a martensitic steel grade that is capable of developing hardening Cu-based precipitates with exposure to an artificial aging procedure [10].

Soaking cast 15-5 at 1075° F (referred to as a H1075 heat treatment) would achieve a minimum hardness of 32 HRC, an elongation of 13%, and a 0.002 yield strength of 862 MPA [11]. For the sword blade submitted in last year's competition, 15-5 in the H1050 condition was utilized, which theoretically imparted a slightly higher yield strength and lower ductility than H1075. Hardening at any lower temperature would further decrease ductility, fostering concerns of an overly brittle spike, which may be at risk of fracture in bending. The team believes 15-5 in the H1050 condition performed exceptionally well in last year's sword, undergoing extreme stresses in cases of deliberate misuse. 15-5 in the H1050 condition will be used again this year.

The team also conducted a formal material selection process known as the Ashby process to try to find superior alternatives to 15-5 PH if there were any. The best option resulting from this process was quenched and tempered 4130 alloy steel. Unfortunately, this option fell short of the properties displayed by 15-5, so no change in material was made.

The material chosen for the axe handle was Osage orange wood. This wood is notably strong, high-density, and has exceptionally straight grains that enable large impact loading without cracking or splitting. Osage orange is also used for tools such as long bows, which also face large amounts of force during use. Alternatives for consideration included ash or hickory if Osage orange was unavailable.

Mold Design and Casting

Mold design included a sprue, gating, risers to address porosity concerns, and bleedoffs to maintain the edge quality of thin portions of the axe [Fig B.1]. The final axe head mold had a blade length of 6 inches from tip to tip and a spike of 4 inches, similar to several historical examples the team found [6]. The blade of the axe head was composed of a 180° semicircle with a radius of 3 inches, and it had an edge with $\frac{1}{8}$ inch thickness tapered from $\frac{3}{8}$ inch. The spike had a base of 1 inch by $1\frac{3}{4}$ inch that tapered to a point. The eye of the axe consisted of an oval opening with a $2\frac{1}{2}$ inch major axis and a $\frac{3}{4}$ inch minor axis, as well as $\frac{1}{4}$ inch walls. A slight taper was added to the eye so that the bottom opening was smaller than the top, ensuring a tight fit with the handle when the wedge is applied, and the eye material is spread. $\frac{1}{2}$ inch bleed offs were added around the blade and spike. Gating to the axe head and spike was $\frac{3}{4}$ inch and $\frac{1}{2}$ inch wide, respectively. All gating was $\frac{1}{4}$ inch thick, and risers (20 mm radius, 36 mm height) were located on either side of the eye.

Multiple iterations of mold design occurred, and several simulations were run in MAGMASOFT to analyze porosity and fill quality of the axe head [Fig B.2]. These simulations informed riser design to ensure a safe margin, minimizing porosity in the axe head. A core box

was also designed and 3D-printed in PLA to create a chemically bonded sand core for the eye of the axe [Fig. B.3]. Both parts of the mold pattern (drag and cope) were 3D-printed in PLA and mounted to a board for use in a flaskless molding system for chemically bonded sand.

Specifically, a phenolic no-bake binder system in silica sand was used as the mold medium. An alcohol-based mold coat was applied to the mold cavity for improved surface finish. Before pouring, the cope and drag were fastened together at the seal lips with Zip Stik by ASK Chemical to avoid slippage or misalignment of mold components. The core was fastened to the coreprint by the same method. 15-5PH Stainless was poured at 2850°F

Furthermore, chemically bonded sand was used as it is cost-effective, intuitive to work with, and cures rapidly in air. This method allowed for a quick set-up and turnaround so that more time could be preserved for heat treatment and processing. Furthermore, sand casting was chosen over more time-consuming methods, such as investment casting, since the axe was not going to be left with an as-cast finish and was going to be polished regardless. Chemically bonded sand was preferred over green sand for its ability to maintain mold shape during a pour while providing a better surface finish without manufacturing time or cost by a large factor.

Treatment and Post-Processing

The gating system was removed from the axe head casting using an angle grinder. Solidified risers on the face of the casting had much larger section areas than the gates, so a partner saw with a cutoff wheel attachment was used for their removal. The casting was homogenized at 1900°F for 1 hour, followed by cooling in air, to dissolve secondary phase particles into the matrix and relieve internal stresses. An angle grinder with a small cutoff wheel was used to remove bleed-offs from the blade and spike. A pedestal grinder with a coarse grinding wheel was used to remove burrs and flashing. An angle grinder with a 60-grit flap disc was used for basic surface clean-up and redefinition of bevels.

The casting was then precipitation hardened by soaking at 1050°F in an electric box furnace for 4 hours, followed by cooling in air. After sandblasting, surface grinding was completed using a belt sander with 2" x 72" belts at 100 grit and 320 grit. Wet-sanding was completed by hand with sandpaper in the following progression of grits: 400, 600, 800, 1000, 1500, 3000. A pedestal grinder with a fabric buffing wheel attachment was used for polishing, with a 5000-grit coarse polishing compound (rouge) for the first step and a 10000-grit fine rouge for the second step.

Handle and Assembly

For the handles, four 24-inch rectangular blanks were cut from green Osage orange logs with a bandsaw. The blanks were allowed to air-dry overnight, leading to a release of internal

stress and subsequent warping. The blanks were passed through a jointer and a planer to render the blank faces parallel and 90° again and achieve new dimensions of 2 ½ x 1 x 24 inches.

The handle was designed to have a 5 ½ inch-long taper that reduces the width of the handle from 2 ½ inches at the top to 1 ½ inches at the bottom. This taper starts 2 inches from the top end to provide room for fitment to the eye of the axe. Chamfers along the length of the handle were cut with a spokeshave and a rasp to leave ¼ inch of flat edge on all four faces, providing the handle with an octagonal cross-section.

The eye of the handle was traced to match the eye of the head and was cut to size with a chisel and fine-tuned with a file. Once the eye of the handle was a tight fit with the eye of the head, the slit was cut in the eye of the handle to be 1 ¾ inches below the end to match the height of the eye of the head. The head was then forced onto the eye of the handle, and a wedge was cut to the thickness of the kerf plus the space between the handle and head on the top, and the width of just the kerf on the bottom to ensure an extremely tight fitment for the handle to the head. The handle was then stained, and the stain was allowed to soak overnight, followed by a lacquer top coat finish.

Trial Iteration

The team completed an initial iteration of an axe head using the core design and a simplified version of the mold described above. The molding was completed using phenolic resin-bonded silica sand, prepared using a Tinker Omega mixer. The mold used for the trial iteration did not contain risers, but was poured into a makeshift sprue directly located on the spike of the axe head cavity. The trial casting was poured with 316 austenitic stainless steel at 2822° F. The axe head was annealed at 1950° F for 1 hour, then allowed to air-cool. The handle was constructed of white maple.

After casting, risers were removed with an angle grinder and a cutoff wheel. A pedestal grinder was used to remove bleedoffs and flashing, as well as give the blade a rough bevel. During processing, major porosity was visible in both the axe blade and the spike just below the placement of the risers.

The trial axe head [Fig. E.4] went through a destructive impact test. Testers swung the axe using both the blade and the pick to strike a wooden pallet. The blade did not sustain any damage during the testing, but the tip of the spike brittle-fractured upon striking the wooden pallet, lasting less than 20 swings. The handle also formed a crack through the top end by the time the testing was completed.

Testing

Hardness values for the axe in the H1050 condition were collected using a mechanical hardness tester. The two collected hardness values were 31 HRC and 22 HRC. Additional tests were not performed due to technical difficulties with the hardness tester, as well as time limitations. What resulted was quite a large error between the two readings and a lack of accuracy. 15-5 PH in a fully annealed state should be approximately 35 HRC, and even harder after a H1050 heat treatment [6]. Qualitative evidence of hardening appeared during post-processing as grinding became noticeably more difficult after solution heat treatment.

A backup axe (which followed an identical procedure to that of the final submission) with an intentionally blunted spike and blade was qualitatively tested for deformation and fracture toughness by hitting full-force against a wooden 4x4. After approximately 20 full wind-up swings, neither the edge nor the spike experienced any visible plastic deformation or cracking, and the head remained securely fastened on the handle.

Discussion

The primary challenge occurred during the design phase of the project, in attempts to get a part that was under the weight limit of 1.5 kg without sacrificing critical features. In the end, the design had to have no langets or belt clips to stay within the weight constraint for the size of the head that we wanted. The team felt that reducing the size of the head to allow for these features would have been a larger detriment to the axe's performance than the removal of the langets and belt hook.

The mechanical design of this axe was intended to ensure simple and straight-forward crafting, especially with regards to the handle. A previously discussed improvement to the straight handle profile would be the presence of a swell or pommel at the end. This would act to prevent slipping in the palm of the user, especially in the midst of a swing. A pommel was removed from the design, not out of necessity, but simply for ease and efficiency of fabrication.

The 3D-printing of the axe head pattern was also a major obstacle and ended up being much more time-consuming than anticipated. Due to repeated technical difficulties, multiple attempts to print were required before a print of satisfactory quality was obtained. This part of the project set back progress on a physical prototype by over 2 weeks, forcing them to focus efforts on other areas of the submission in the meantime. Other complications in the regime of project timing included delayed communications with the industry partner and difficulty accessing resources for post-processing.

The largest areas for improvement in this project are time management, process planning, and delegation of work amongst team members. Initially, setbacks were due to a lack of concrete deadlines agreed upon by the team. Setbacks continued when leadership commonly failed to uphold the established timeline or hold team members accountable for completing work on time. Team meetings had a tendency to veer off of a pre-determined topic and usually did not fulfill the

team's goals. In the second half of the project, with pressure from the final deadline, meeting productivity improved significantly over time.

The handle cutting and shaping, patternmaking, molding, axe head casting, heat treatment, post-processing and assembly, all occurred over the course of 2 months, with the majority of this work being completed within the span of 2 weeks. Ideally, further hardness testing and non-destructive evaluation of casting quality (i.e. ultrasonic scanning) would have been completed if time allowed. The team also considered laser etching a design onto the axe head, or an engraving and inlay on the handle. These extra steps could not be attempted considering the time crunch, no less without risk of a critical error.

The key takeaways from this year's project are to create 3D printed prototypes much more often in the design phase of the weapon and of the mold pattern, get in contact with the team's industry partner as soon as possible in the project (well before the team is at the point that the industry partner is needed), leadership devoting more time to creating a realistic project timeline and keeping it updated as the project proceeds, and finally, asking for help from outside sources more often instead of just wasting time with trial and error.

For future projects, teams should aim to establish a mechanical design and physical prototype of the part much earlier than previous years. A first iteration of mold design and printing of pattern parts should, in an ideal case, be completed by December each project year. More time should be committed to the development of ambitious designs and aesthetic exploration before project work even begins. In general, a positive change in practice would be spending more time in the shop, doing hands-on work, instead of in the office, deliberating over design changes. Project leadership must devote more focus to the creation of a realistic project timeline, along with persistent communication about timeline reminders and updates with the rest of the team. It is highly recommended that future teams broaden their base of support by reaching out to more than one entity for necessary resources and services - not only for the casting submission, but for the project video as well.

References

- [1] Steel Founders Society of America. “Technical Report Requirements”. (2025) <https://www.castinsteel.net/technical-report-requirements>
- [2] American Foundry Society, “About Metalcasting: History”. <https://www.afsinc.org/about-metalcasting>
- [3] Duncan, A. A. M. “The Community of the Realm of Scotland and Robert Bruce: A Review”. *The Scottish Historical Review*. (1966) <https://www.jstor.org/stable/25528661>
- [4] Battle of Bannockburn Family History Project. “Henry de Bohun”. *University of Strathclyde Glasgow*. <https://www.strath.ac.uk/studywithus/centreforlifelonglearning/genealogy/geneticgenealogyresearch/bannockburnprojectdocumentary/bohunsirhenryde/>
- [5] DeVries, R.K., Smith, R.D. *Medieval Military Technology, 2nd ed.* University of Toronto Press. (2012) ISBN: 9781442604995
- [6] *Horseman’s Ax of Cardinal Ippolito de’ Medici, 1511–1535.* The Metropolitan Museum of Art, New York, NY. <https://www.metmuseum.org/art/collection/search/26548>
- [7] *Horseman’s axe with a disc-shaped guard, 1600-1650.* Leeds, War Gallery. <https://royalarmouries.org/collection/object/object-1472>
- [8] “Cast in Steel Horseman's Axe Expert Discussion”. *YouTube*, uploaded by SFSA. (2025) <https://www.youtube.com/watch?v=oauFYxJvYCY&t=19s>
- [9] United States Department of Agriculture. "One Moving Part: The Forest Service Ax Manual", pp. 99-112. <https://www.pcta.org/wp-content/uploads/2020/12/USFS-Ax-Manual-2020.pdf>
- [10] Couturier, L., De Geuser, F., Descoins, M., Deschamps, A. “Evolution of the microstructure of a 15-5PH martensitic stainless steel during precipitation hardening heat treatment”. *Materials & Design*, vol. 107, pp. 416-425. (2016) <https://doi.org/10.1016/j.matdes.2016.06.068>
- [11] “ARMCO® 15-5 PH® Stainless Steel: Precipitation Hardening Stainless Steel Product Data Bulletin ” *AK Steel Corporation*. (2007) https://www.spacematdb.com/spacemat/manudatasheets/15-5_PH_Data_Sheet.pdf

Appendix A: Design Process

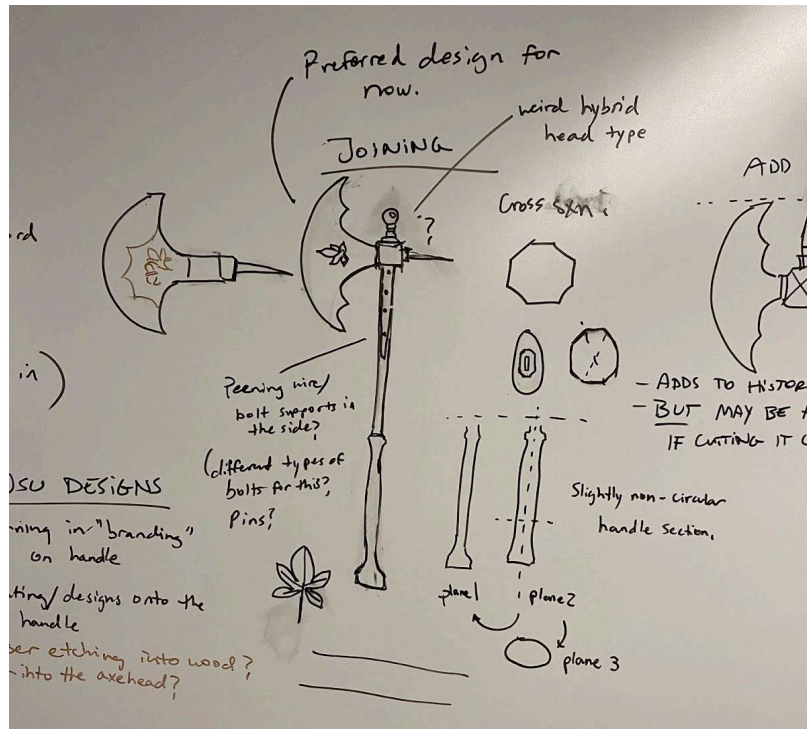


Fig A.1: Initial Design to Determine Axe Visual Components

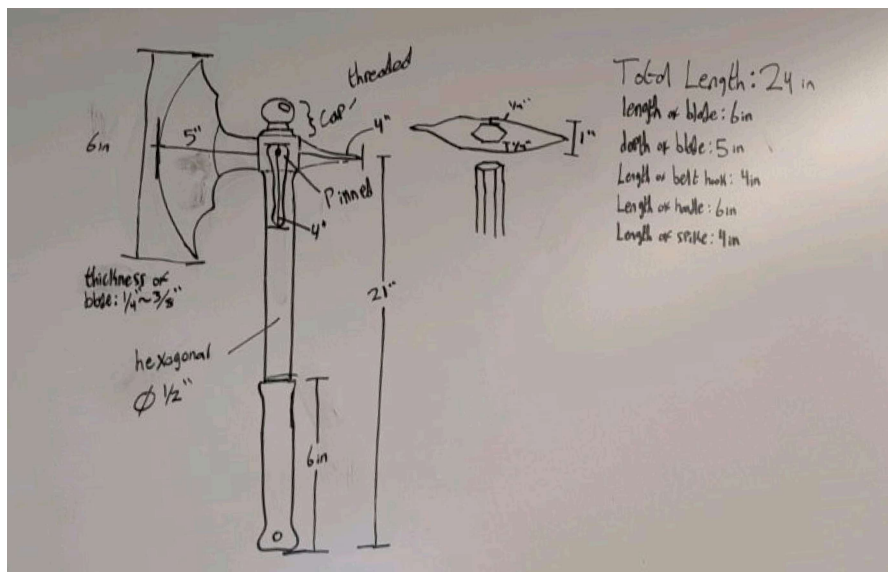


Fig A.2: Initial Estimated Axe Dimensions Based on CIS Limitations and User Comfort

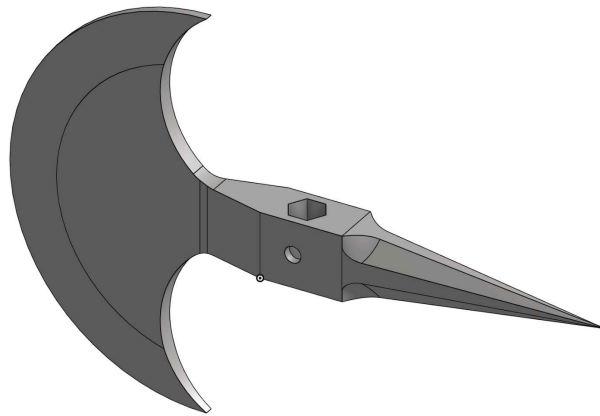


Fig A.3: First CAD Iteration of Axe Head

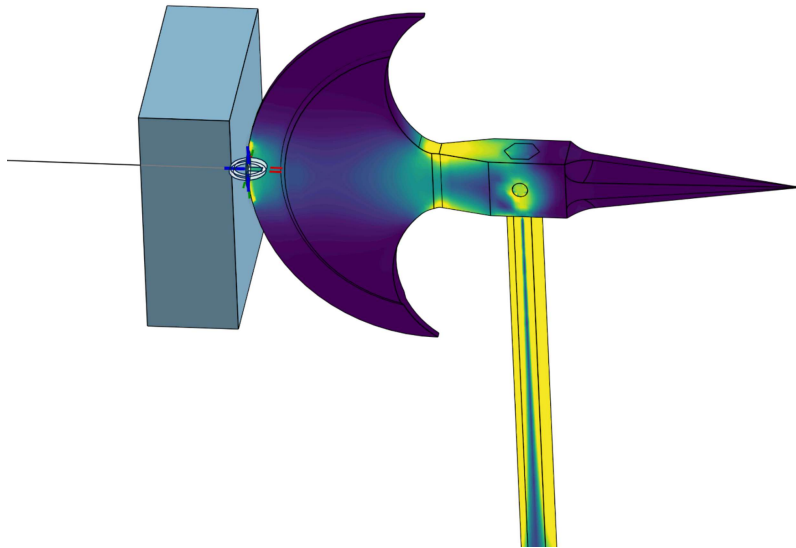


Fig A.4: Stress Simulation of First Axe Iteration [von Mises stress (psi)]

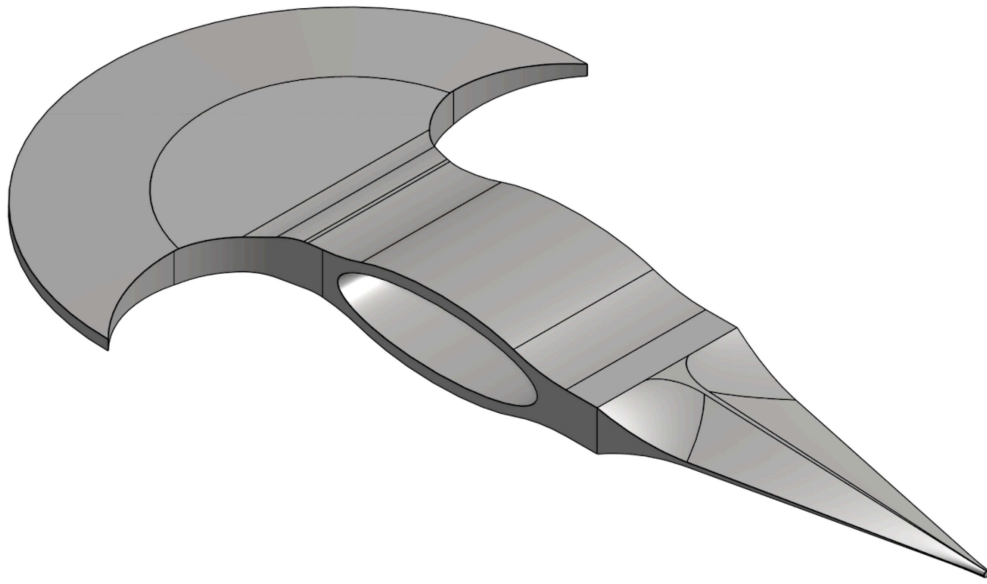


Fig A.5: Second CAD Iteration of Axe Head

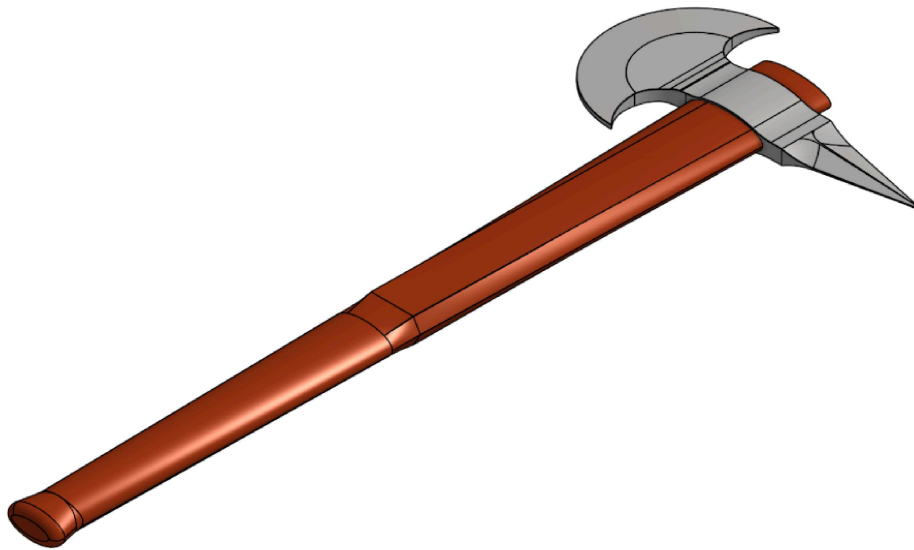


Fig A.6: CAD Model of Entire Axe

Appendix B: Mold Design

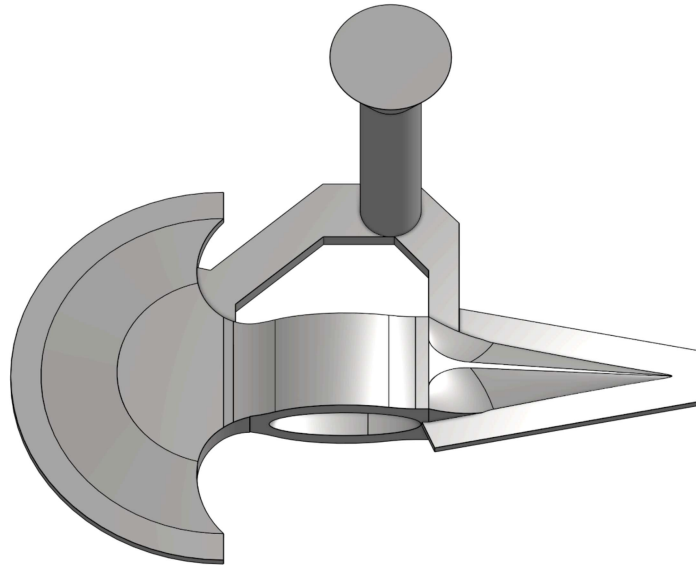


Fig B.1: Final CAD Iteration of Axe Head with Gating and Bleed-Off

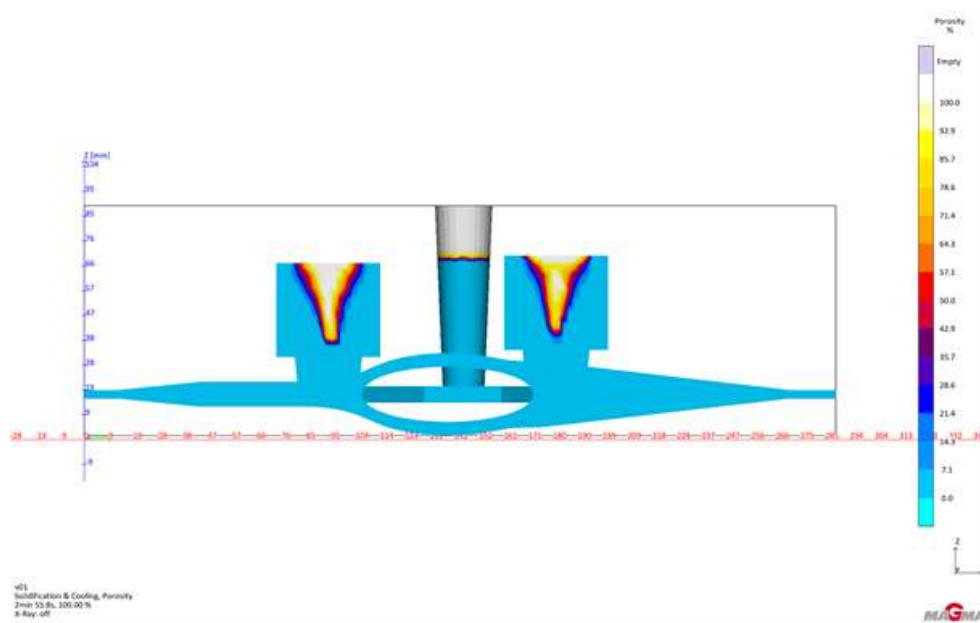


Fig B.2: MAGMA Simulation Results With Risers

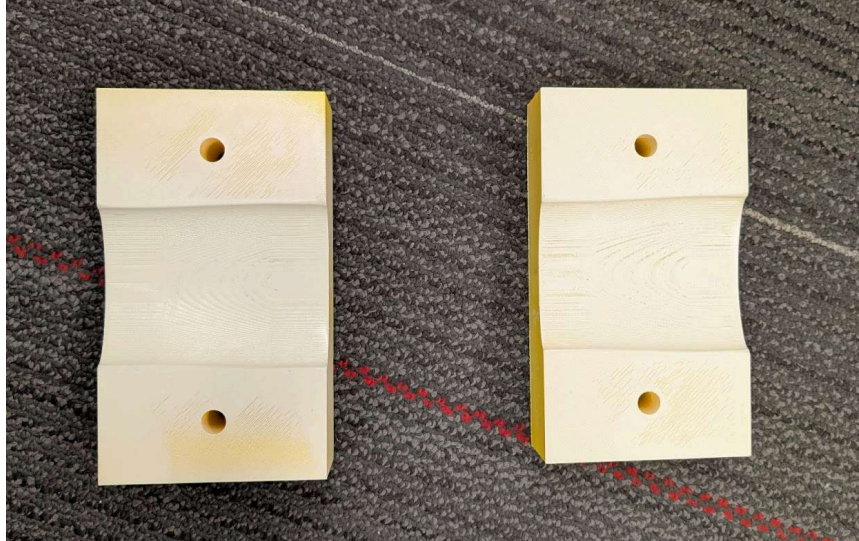


Fig B.3: 3D-Printed Core Box Mold



Fig B.4: 3D-Printed Axe Head Molds

Appendix C: Fisher Cast Steel Final Pour



Fig C.1: Final Chemically Bonded Sand Mold (Drag)

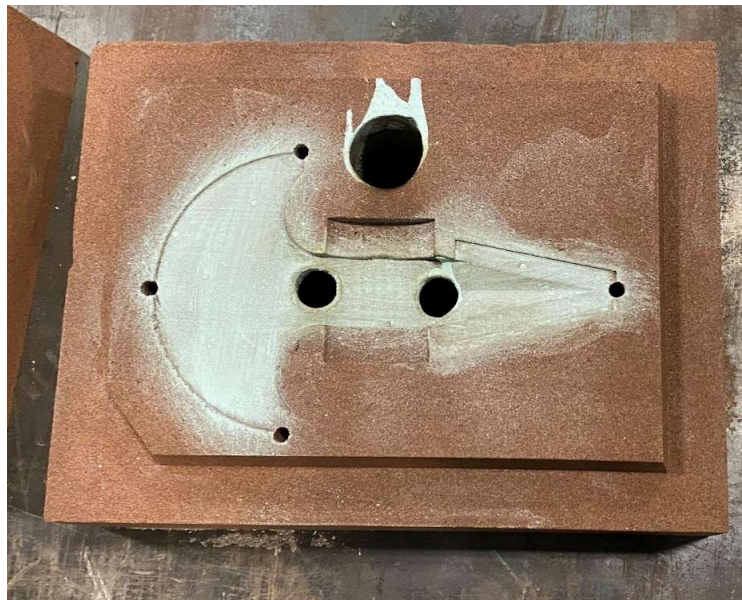


Fig C.2: Final Chemically Bonded Sand Mold (Cope)



Fig C.3: Pouring at Fisher

Appendix D: Processing



Fig D.1: Progression of Axe Head Post Processing



Fig D.2: Progression of Axe Head Polishing

Appendix E: Hanging the Axe Head



Fig E.1: Preparing Handle



Fig E.1: Preparing Kerf and Wedging Axe

Appendix F: Creating the Test Axe



Fig F.1: Chemically Bonded Sand Mold After Pouring



Fig F.2: Cooling, Glowing Axe Head



Fig F.3: Cooled Axe Head Before Processing



Fig F.4: Finished Trial Axe With Processed Axe Head and Finished Handle; After Testing With Broken Spike Tip