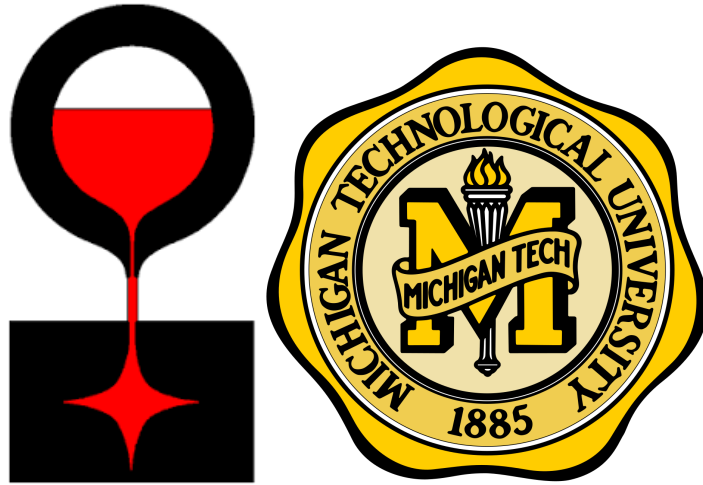


SFSA Cast In Steel 2026 – Horseman's Axe
Technical Report
Michigan Technological University – Labyak's Labrats



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Introduction

Cast in Steel is a nationwide casting competition in which teams compete to design, cast, assemble, and test a variety of different weapons, ranging from historical items such as George Washington's sword to more fantastical items such as Thor's hammer. The competition was created by the Steel Founder's Society of America (SFSA). The goal of Cast in Steel is to give students the opportunity to pursue knowledge of making steel products via casting. The competition promotes the advancement of the steel casting industry by introducing the next generation of engineers to the manufacturing and design process. Cast in Steel also fosters professional connections between students and industry partners, as each team is required to have a corporate sponsor to advise and aid them during the engineering process.

Historical Background

The development of plate armor began in Europe during the 13th century, and was refined over the next two centuries until it almost completely replaced chain mail as the dominant armor type (Breiding [1]). The horseman's axe rose to favor in the 14th and 15th centuries, as combatants sought ways to smash, stab, and slice through heavy plate armor. Traditional weapons such as broadswords struggled to cut through the more technologically advanced armor. The horseman's axe could deliver a substantial amount of concussive force, which was needed to pierce the thick metal, and it achieved this via three tools: a main axe blade, a spike at the top of the axe head, and a back tool that typically came in the form of a spike or a hammer. The axe blade was designed to cleave through less armored areas or shields. The spike was designed to thrust into an enemy and pierce the plate armor. The back tool varied in shape depending on its purpose, but it always provided added mass to increase the weapon's inertia, creating a larger impact force. There were also langets - long structural support struts - that ran down the axe handle to provide stability and prevent the handle from being cut by an opponent (Price, [2]). While some methods of assembly cast each part individually and then assembled the axe head via pins, the most efficient way was to cast everything at once: the spike, blade, back tool, and langets as one unified piece (Gorznow, [3]).

To ensure historical accuracy, our axe head maintains the classic characteristics of the horseman's axe. The back tool chosen was the crow's beak, or bec-de-corbin (Price, [2]). The spike sits atop the axe head. Although the langets needed to be cast separately to prevent solidification issues, the main cutting implements were cast as one piece. Assembling the axe this way preserved the historical process of casting the head as one. A hole in the middle of the axe head was drilled to allow for a leather strap to fit in, acting as a belt hook. Our handle's material was also selected to maintain accuracy - the wood is ash, one of the most favored materials of the time. Ash is well known for its strength and flexibility, absorbing impact and shock with ease. The grain is also straight, making it easier to shape and giving it a smoother finish (Flippova, [4]). The shape of the handle is oval, to provide edge indexing. This allowed the combatant to know where the blade was instinctively in the middle of a battle. To finish our handle, linseed oil was used instead of a modern day chemical. By combining modern day steel with the engineering design of the past, our axe represents the best of both worlds.

Design Process

Initially, each group member made a design based on historical research. These were looked at as a team and discussed before one design was selected to be moved forward. The designs were evaluated on historical accuracy and feasibility to cast. The first changes made were to improve casting success, the biggest factor being adding chamfers or fillets on all the edges. Once that was finished, the weight also had to be taken into account. Microsoft Excel was used to calculate the weight. This included estimations for the axe head assembly, the handle, and the pins, shown in Table [1]. Many changes were made for lowering weight such as adding decorative holes in the blade, thinning the main body of the axe, and reducing the size of the spike, the back tool and the blade. As our material wasn't selected yet, the density of steel was assumed to be 0.29lb/in³, which is on the higher end for steel density. The handle was also part of this estimation, with density of wood being assumed to be 0.0353lb/in³, which is a bit higher than average density of most hardwoods. This ended up with the axe head starting at an estimated weight of 2.47lbs, and after many changes were made, ending at a weight of 2.16lbs. The final measured weights are shown in Table [2].

Another major design change we made had to do with the attachment of the handle. Originally, the plan was for the head to be composed of two parts. One piece that included the spike and the lagnets, and the other piece that included the blade and the back tool. These would be assembled by placing the blade/back tool piece on top of the handle, then having the langet sit on top and hold everything together, shown in Figure [1]. This caused several problems though, first being that the lagnet/spike part was too thin and long to be reasonably cast. There was also very little surface area preventing the connection from the axe handle to the axe head from breaking, as only the pins were holding it to the axe head.

All of those problems informed the decision to cast the blade, back tool and spike of the axe as one part, and cast the lagnets as another. A tang was added to the axe to be secured into the axe handle. Once the tang was secured inside of the handle, a pin was driven through the handle to provide more strength.

Material Selection

Since axes are impact-based tools that must hold up over cycles of high shock and vibration, the steel had to be able to take a beating without rolling or cracking. The material chosen for the axe head was AISI 4340 steel. It is a low alloy carbon steel, known for its unique combination of high strength and toughness. It's often used for heavy duty applications such as transmissions, landing gears, and automotive frames. Table [3] shows the material's properties (McClements and Lichtig, [5]).

The carbon content of 4340 steel ranges from 0.37% to 0.43%, making it harder than a typical low carbon steel (McClements and Lichtig, [5]). It is an extremely tough material that can absorb high amounts of energy. This is due to the nickel content of the steel - ranging from 1.65% to 2.00% - which provides ductility by altering the microstructure of the grain without sacrificing the hardness of the steel (Xia, [6]). Another key feature that 4340 steel has is its deep hardenability. During heat treatment, the steel is heated and then quickly quenched in oil. The carbon redistributes throughout the material (Fusion, [7]). 4340 steel has higher levels of chromium and molybdenum, which slow down the cooling process and allows the carbon to penetrate deeper into the steel, allowing the entire axe head to become martensite. This increases the hardness of the material evenly throughout the axe head (Xia, Zhang, Li, and Xu,

[8]). Table [4] displays a breakdown of the elemental composition of 4340 steel. This same ductile nature gives it a high fatigue resistance as well, allowing the axe to withstand repeated impact over a long period of time. Also, if the axe fails, the edge is more likely to roll versus chip, which makes the blade far easier to repair.

Casting Process

In order to ensure a clean cast, our sponsor, Bay Cast, ran simulations on our axe head's design. Our initial design had the langets attached to the axe head, as we wanted to keep the casting process as historically accurate as possible. However, the simulations revealed solidification issues within the mold. As such, the langets were removed from the CAD model and cast separately from the rest of the axe head. The molds are shown in Figure [2 and 3]. Bay Cast commissioned the 3D printed sand molds from Humtown.

At their facility in Bay City MI, Bay Cast prepped the molds, cast the metal and shook out the axes. The 3D printed molds were set into steel flasks along with the gating and risers. Resin sand was then rammed into the remaining space to create a finished mold. A two ton induction furnace was used to melt 3500 pounds of AISI 4340, the furnace was tapped into a ladle where it was transported by an overhead crane to the molds and poured as seen in Figure [4]. Once the axes cooled overnight, the axes were shaken out and risers cut off, the shaken out axes are shown in Figure [5].

Annealing

As AISI 4340 has a general machining rating of 10-25%, it was decided to anneal since the machinability rises to 50-57% (SuppliersOnline, [9]), making the axes easier to machine.

As 4340 is susceptible to decarburization, which is the breakdown of carbon content within the material at high temperatures when exposed to oxygen. When annealing, the axes were placed into aluminum annealing bags, as shown in Figure [6], to protect them. The axes were annealed to find a spheroidized structure over pearlite for increased machinability. This process was simplified to 1440°F for one hour, furnace cooled to 1000°F, and air cooled to room temperature to fit the capabilities of the furnaces in the Michigan Tech Foundry.

Machining

Machining was completed by the Michigan Tech Manufacturing and Mechanical Engineering Technology (MMET) machine shop. To prepare the raw casting for machining, the axe heads needed to be sandblasted, and the risers left over from the casting process needed to be removed, as shown in Figures [7 and 8]. To remove the raw material, an angle grinder was used to cut off the bulk of the steel and clean up the edges of the blade.

Two main risers on the axe head were left uncut - the large cone on the back and the long riser extending where the handle will go, as shown in Figure [9]. The long riser was machined down into a rectangle extending from the axe head - in the final assembly, this would go into an interference fit hole in the wooden axe to provide more structural stability. The large cone was initially left on so that the axe head could be oriented easily throughout the machining process. Soft jaws were 3D printed to hold the axe head horizontally between the blade and the crow's beak. The large cone was then machined flat on the top surface, and cross slots and a threaded hole were added to the flat. This made it possible to attach it to a 3in width cube with

matching channels and counterbore features to act as a highly adjustable fixture, and allowed for precise machining of the rest of the key features in five different orientations.

The next step in the machining process was to mill the flat area of the long riser to have more areas to indicate off of. Then, the clover leaf pattern on the blade was drilled. The spike was milled into a conical point, and then the part was flipped upside down to machine the interface between the axehead and the handle. A perimeter pass was run to clean up the edge, and then the axehead was placed back into the soft jaws to remove the large cone. The langets unfortunately cast poorly, but the runner that linked them all together was sound. The runner was thinned down to width and the edges were machined to length. The holes were then drilled down the langet. The pins were machined out of brass to fit the holes drilled.

Quenching

After machining the axe, the next step was to quench and temper the axe to increase the strength and hardness. We decided to oil quench at 1550°F. This was due to the fact that quenching with oil would help increase the strength of our axe and reduce cracking during the quenching. The temperature 1550°F was also selected because it helps increase the toughness/strength of the axe.

The quenching process includes heating up our axe head in a furnace and heating to 1550°F. Then, after reaching our desired temperature the axe head is then placed into oil until the temperature is reduced. Then we tempered that axe at 400°F for 2 hours to reduce the hardness and to make the axe less brittle. For tempering, a decarbonization bag was once again used to reduce the risk of decarbonization.

Testing

A Rockwell hardness test was performed on our axe head and it was found to have a hardness of 53. This indicates a softer steel which is less likely to chip and much easier to sharpen. Additional visual testing was also performed to ensure that the axe would retain its components during testing. Slight dimples as a result of casting are present on the axe blade and area underneath the top spike, but were deemed as not deep or threatening to the integrity of the axe.

Performance Analysis

For performance testing we hit a watermelon, shown in Figure [10]. We used both the blade of the axe as well as the crow's beak, and the axe suffered no damage. There was significant crushing damage to the watermelon, showing the crow's beak functions as a functional piercing tool. The axe blade delivered clean cuts through the entire watermelon with minimal resistance

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Appendix

Figures

Figure [1]: Original Design Exploded View

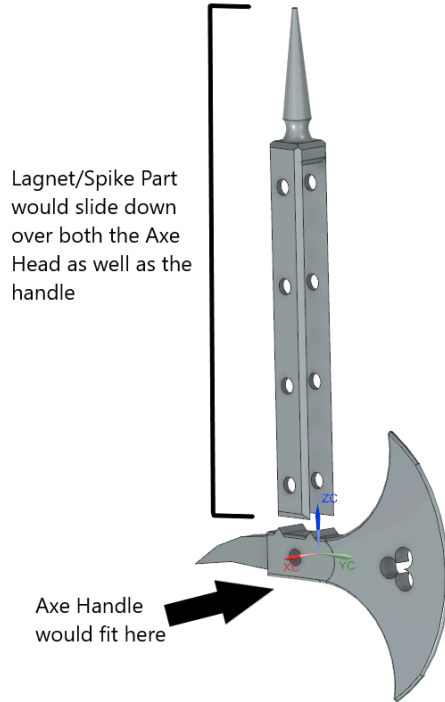


Figure [2]: Axe head mold

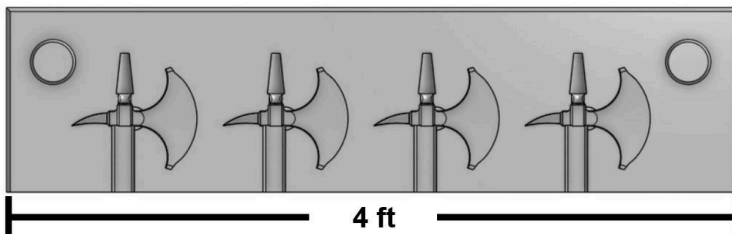


Figure [3]: Langets mold

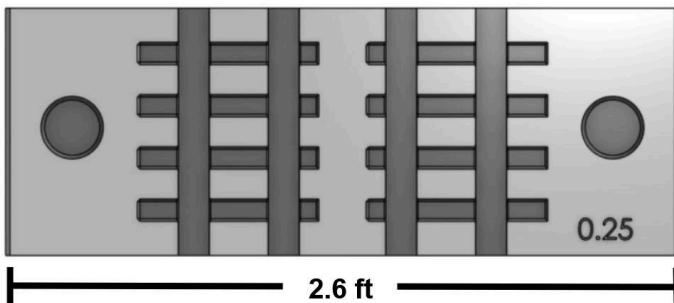


Figure [4]: Steel poured into mold



Figure [5]: Axes attached to runner post shake out



Figure [6]: Aluminum annealing Bags



Figure [7]: Post sandblasting



Figure [8]: Cutting off the raw material



Figure [9]: Material leftover after the riser removal process

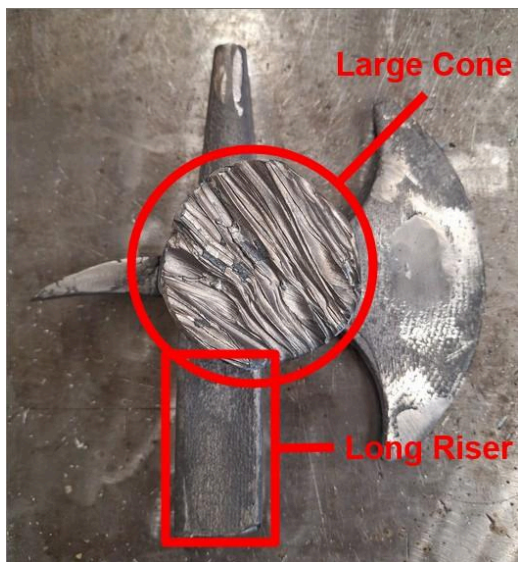


Figure [10]: Watermelon after performance testing



Tables

Table [1]: Weight Estimations Spreadsheet

Part	Volume (in ³)	Weight (lbs)	Density (lbs/in ³)	Final Weight Estimation
Axe Head	7.4496	2.1604	0.29	3.19
Lagnet	0.9160	0.4993	0.29	
Wood Handle	15.9043	0.5614	0.0353	
Pin(s)	0.1243	0.0360	0.29	

Table [2]: Final Weights

Part	Weight (lbs)	Overall Weight (lbs)
Axe Head	1.964	3.3
Handle	1.000	
Pin	0.036	

Table [3]: Material Properties of annealed 4340 Steel

Property	Value
Density	0.284 lb/in ³
Yield Strength	125,000 psi
Hardness (Rockwell B)	100

Table [4]: Percent Composition of 4340 steel (McClements and Lichtig, [5])

Element	Required %	Actual %
Iron	95%–96%	95.009%
Nickel	1.65%–2.00%	2.49%
Chromium	0.70%–0.90%	0.90%
Manganese	0.60%–0.80%	0.72%
Carbon	0.37%–0.43%	0.38%
Molybdenum	0.20%–0.30%	0.20%
Silicon	0.15%–0.3%	0.29%
Sulfur	0.04%	0.003%
Phosphorus	0.03%	0.008%