SFSA Cast In Steel 2026 – Horseman's Axe

Technical Report

University of Wisconsin- Madison – The Madtown Axemen

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Abstract

The Steel Founders' Society of America (SFSA) Cast in Steel competition challenges students to design and manufacture a steel component using casting processes while applying modern engineering techniques. As stated by SFSA, this competition was created to encourage students to learn about making steel products using casting processes and applying the latest available technology. This project focuses on the development of a historically accurate horseman's axe that meets strict dimensional and performance constraints, including a maximum weight of 3.3 lbs and a length of 31.5 inches. The objective of this work was to design an axe that balances historical authenticity with modern manufacturing, mechanical performance, and repeatability.

The design process began with research into traditional horsemen's axes. These axes were optimized for one-handed use on horseback and required efficient force transfer through a lightweight structure [1]. Using these principles, the team developed and refined a CAD model to optimize blade geometry, spike configuration, and overall weight distribution. Attention was given to concentrating mass near the blade edge so as to help maximize cutting effectiveness and minimize excess material in non-critical regions. Design modifications also addressed casting-specific factors such as draft angles and uniform section thickness. Smooth geometric transitions were used to improve mold filling and reduce defects.

Investment casting was selected as the primary manufacturing method due to its ability to produce complex geometries with high dimensional accuracy and an as-cast finish. This approach enabled the integration of the blade and spike into a single component while minimizing machining requirements. For the casting process, Signicast Inc. sponsored the pour and provided some non-destructive testing. Before casting, MagmaSoft was used to design adequate gating and to ensure that non-fill and porosity would not occur.

Post-casting operations included gate removal, grinding, and surface finishing to improve dimensional accuracy and surface integrity. A controlled heat treatment process was applied to achieve the desired balance of hardness and toughness in the 4140 steel alloy, targeting a hardness above 50 HRC for optimal edge retention and impact resistance. Surface finishing and polishing were performed to reduce stress concentrators and improve fatigue resistance. Once the axehead was completed, it was attached to a white ash handle to reduce overall weight and assist in shock absorption. Electroetching was also completed, but solely for aesthetic purposes.

The final product satisfies all competition requirements in terms of weight, dimensions, and material selection while demonstrating the advantages of casting technology in producing complex, high-performance steel components. This work highlights the integration of historical design principles with modern engineering and manufacturing methods to produce a functional and manufacturable horseman's axe.

Historical Background

The axe was used in mounted combat in Eastern Europe and parts of Central Asia between the 16th and 18th centuries. These weapons were designed for cavalry soldiers who needed something lightweight and easy to control with one hand while on horseback. The most identifiable features of this design are the combination of both a front cutting blade and a rear piercing spike. This blade was used for slashing, while the rear spike allowed the user to penetrate armor. These axes were also designed to be significantly more compact and balanced than larger, two-handed axes. The longer handle allowed for the user to have longer reach, while the thin profile further enabled easy one-handed use. Many designs also included langets, which are metal strips along the handle that help reinforce it and prevent damage to the axe.

CAD Modelling

The design process began with research into historically accurate horseman's axe geometries, specifically focusing on the blade curvature, spike inclusion, and overall proportions. These features were all taken into consideration and translated into the initial 3D CAD model, which served as the foundation for different iterations of the design. The initial design included a spike on the back, a large spike on the top, and a large axe face. This initial design was 8.71 inches tall and 9 inches wide, which was larger than anticipated and desired.

Multiple design iterations were developed, which were done to refine the geometry while considering the weight and size, which had not been previously done. The other things that were taken into consideration were the ability to cast and whether solidification shrinkage or porosity would occur. The adjustments that were made to the blade thickness, spike length, and the eye geometry were all in an effort to improve not only cutting efficiency but also stability and structural integrity.

In addition to the functional performance, the CAD model was also recreated to ensure that it would successfully cast. Draft angles were used to make sure that the removal of the part from the tree was easily completed. Sharp internal corners were also minimized to reduce stress concentration and improve metal flow during solidification. The section thicknesses were also adjusted to promote a more uniform cooling and reduce the likelihood of shrinkage defects.

The final CAD design [Fig. 1], now measures 6 inches from top to bottom and 7.9 inches long. The back spike was purposely designed to be longer than the actual length required to account for possible nonfill that could occur in the tip. The top spike was also reduced in size to minimize the chance of the user poking themself with the top of it while in use.

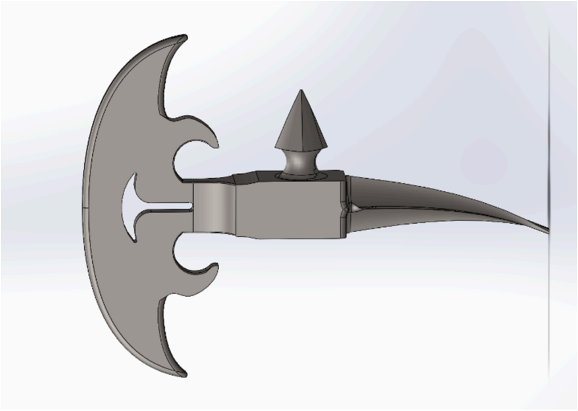

Figure 1. Final SolidWorks CAD model of the axe head.

Alloy selection

The primary considerations when deciding on the alloy were the toughness, impact resistance, and the hardness of the material. To begin this process, martensitic steels, specifically tool steels, were evaluated for their ability to achieve a high hardness. However, the main concern about these steels was that they would not perform well when tested for edge retention and impact resistance. After reevaluating the requirements, 4140 alloy was chosen due to its historical use for axes and being a low-alloy chromium-molybdenum (chromoly) alloy. The inclusion of chromium and molybdenum as alloying elements allows for 4140 to reach a higher strength than alloys that have similar carbon contents. This combination allows it to perform well with impact resistance, toughness, and post-heat treatment hardness. The high hardness that can be achieved through heat treatment can be completed by using a slower rate of cooling, which not only allows for a more uniform hardness profile throughout the material but also reduces distortion.

Simulations

MAGMASOFT simulation software was used to refine gate size, ensuring sufficient flow rates while minimizing turbulence and air entrapment. The simulations focused on identifying areas that could exhibit shrinkage-related defects and refining solidification behavior before casting. These results were important because the part contains several thin sections and pointed features that were more sensitive to non-fill and localized hot spots.

The simulation outputs include Hot Spot FSTime [Fig. 2], Hot Spot [Fig. 3], and Fraction solid [Fig. 4]. These plots provide an overarching understanding of how the solidification front moves through the geometry.

Figure 2. Hot Spot FSTime plot showing the last thermally isolated regions to solidify. The highest values are in the center of the tree.

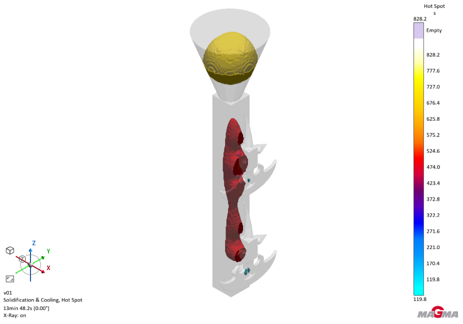

Figure 3. Hot Spot plot highlighting the most defect-prone thermal masses.

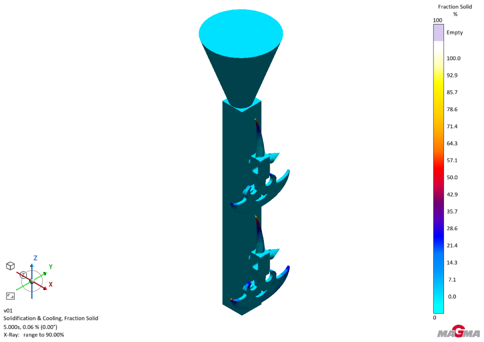

Figure 4. Fraction solid plot showing the progression of solidification throughout the full assembly.

The simulation results indicated a favorable solidification pattern, as the largest thermal mass was located in the sprue rather than within the axe geometry [Fig. 3]. This suggested that shrinkage was directed toward the feed metal, reducing the risk of internal defects in the blade. Hot spot analysis identified several smaller isolated regions along the central feed path. Upon further investigation, the hot spots observed near the face of the axe were determined to be located within the gating system rather than the blade itself [Fig 3]. Additionally, a hot spot observed at the top point of the casting was traced back to a geometric issue in the SolidWorks model [Fig 2]. This feature was corrected before printing, ensuring it would not impact the final casting.

The fraction solid plot also showed that the thinner blade edges and sharp tip features solidified early, which was expected [Fig. 4]. This confirmed these features were sensitive to non-fill, but were still predicted to fill during pouring. Overall, MAGMASOFT simulations played a critical role in determining the correct gating locations and dimensions, allowing for a more efficient and defect-resistant casting design.

3D Printing and Tree Assembly

PolyCast filament and wax printing were both tested to compare performance in surface finish, print quality, and burnout behavior [Fig. 5]. PolyCast was selected for its low ash residue (~0.003%) and ease of post-processing, while wax patterns provided a benchmark for traditional investment casting methods.

Additional wax gating blocks were attached to each pattern to allow for sufficient room during cut-off. All joints between the gating and sprue were fused by melting the contact surfaces. This process ensured proper mechanical bonding at the interfaces, minimizing the risk of separation during the shell building process.

Figure 5. Tree set up for casting. The left is a PolyCast 3D print, and the right is a wax print.

Shell Building

After the wax trees were assembled, the investment molds were built up around them. This involved alternating between hand-dipping the trees in a slurry and coating them with stucco. Zircon silica was used as the aggregate in the slurry and the stucco, with finer particle sizes being used for the initial layers and coarser particles for building out the bulk of the shell. When the shells were complete, the wax and 3D prints were melted and burned out, and the shells were fired. The shells were then ready for preheating and pouring.

Pouring

The pouring was completed at the Signicast-Brown Deer facility. The metal was poured at 2950-2980℉ into preheated shells to ensure complete mold filling and minimize defects. Four separate shells were poured with an average time of 4 seconds. The molds were then air-cooled, and then the parts were cut from the tree.

Non-destructive Testing

Non-destructive testing (NDT) was performed using X-ray radiography to evaluate the internal integrity of the cast components before further processing. This method enabled the detection of subsurface defects, such as porosity, without damaging the parts. The radiographic results indicated that the blade region was free of internal defects. This confirmed that the gating system directed shrinkage away from critical geometry. Minor variations in density seen in the radiograph were consistent with section thickness changes rather than true defects [Fig. 6].

Figure 6. X-ray radiograph used to evaluate internal defects and casting quality.

Pre-Heat Treatment Grinding

Upon receiving the axes from casting, the first step was to remove the gating system. To start the process, a hacksaw was used to remove the bulk of the gating material. Next, using 60-grit sandpaper on a belt sander, the remaining gate connections and the surface oxide were removed. However, due to the geometry of the axe head, multiple crevices were inaccessible to the belt sander. Thus, a Dremel and hand sanding were used to clean up the faces with more angular geometry. Some examples of such spots include the faces of the spike on the back, the base of the spike on the top, and the interior of the detailing cast into the blade face. In addition, preempting possible problems when attaching the handle, it was decided that the edges of the handle hole should be rounded out, reducing the possibility of sharp edges producing stresses on the handle. Next, the top of the handle hole was also levelled out to allow the handle to sit flush against the top of the axe head. Finally, using the same 60-grit sandpaper on the belt sander, the blade edge was beveled to the desired shape.

Grinding before heat treatment allows for greater material removal without the concern for overheating the surface.

Heat Treatment

There were two different methods that were used for the heat treatment process. First, a carbon restoration was done, which was then followed by a marquench. Carbon restoration was done to restore the surface carbon content to match the nominal composition of the base material [2]. The carbon restoration process was done over a total of 4 hours, where the axe heads were held at 1725°F for 2 hours at a 0.45% carbon potential atmosphere. After this, the furnace was turned down to 1610°F for a minimum of 10 minutes. A top cool process was done for 2 hours, then allowed to air cool until an ambient temperature was reached.

Once the carbon restoration process was completed, marquenching was then utilized in an effort to avoid distortion and quench cracking [3]. This was done in an atmosphere of 0.45% carbon potential, where it was austenitized for 2 hours at 1575°F. It was then removed from the furnace and put into a quenching salt that was at 400°F for 15 minutes. Immediately after removal, the remaining quench salt was removed at a rate of 1-3 GPH for approximately 10 minutes to eliminate the chance of corrosion. Once the wash is completed, a snap temper is used to relieve any internal stresses and help to prevent cracking. This was done at 350°F for 3 hours and then cooled to an ambient temperature using a fan. Finally, a temper was done at 400°F for 3 hours, and then air-cooled to ambient temperature.

After heat treatment was completed, an average hardness of 52 HRC was recorded.

Polishing and Electroetching

After heat treatment was completed, oxide buildup was removed from large faces with 120-1200 grit sandpaper on a belt sander. To avoid changing the microstructure of the axe head, breaks were taken periodically to prevent the steel from heating up. To sand rounded or small crevices, hand sanding and Dremeling were utilized using the same steps in grit of sand paper as belt sanding. Then, hand sanding was repeated after the head, langets, and brass pins were attached.

Once the sanding and polishing process was completed, 2 "W"s were electroetched onto either side of the axe on the langets. The design of the "W" was taken directly from the academic crest of the University of Wisconsin-Madison, which was cut out of vinyl stickers. To etch this, a 9V battery was connected to the langet by the positive terminal, and the negative terminal was connected to a cotton swab. This cotton swab was then saturated with salt water, which conducted the current and effectively etched away the top layer of exposed metal, revealing a bright silver "W" at the bottom of the langets. The excess salt water was removed using denatured alcohol to avoid corrosion and rusting.

Handle Construction

Wood was selected as the handle material, as opposed to steel, in order to reduce weight and absorb shock for user comfort. Specifically, white ash was chosen since it is a strong, durable wood that is suitable for tool handles and is commonly used to make wooden baseball bats.

Since the eye of the axe head was slightly unconventional, a parallel-sided hole that did not extend through the entire head, careful consideration was taken when planning how to attach the handle to the head. Two complementary methods of attachment were chosen to ensure the integrity of the axe. The first method took inspiration from a woodworking joint and involved cutting two perpendicular slits in the end of the handle that would be inserted into the eye. Wedges were placed in the slits so that when the handle was driven into the eye, the wedges hit the back of the hole before the handle was fully in place. This drove the wedges into the handle, swelling the wood and locking it in place. The second method was to rivet langets onto the sides of the handle, as is often seen on historical axes. The langets, being riveted to both the handle and the axe head, would further secure the connection.

To make the handle, a rough piece of wood was first split out of the heartwood of a white ash log. This was done to ensure that the piece of wood that would become the handle had no knots, defects, or grain runout, thus resulting in the strongest piece of wood possible. The growth rings were aligned parallel to the direction the handle would be swung. After hewing and planing the wood so that it was a 1 ½” x 1” rectangle in cross section, the end of the handle was reduced in size and shaped so it slid snugly into the eye of the axe head. Two perpendicular slits were cut into this end of the handle so it could be wedged onto the head. Next, the handle was reduced in size and chamfered so it fit comfortably in the hand, and was also tapered slightly to provide a more secure grip. Finally, a recessed section was carved out of the handle for a leather wrap, so the leather would be flush with the rest of the handle. The leather wrap was secured with small brass-coated nails.

Assembly

The final assembly of the horseman’s axe involved integrating the axe head, wooden handle, langets, and end cap into a final design [Fig. 7].

Figure 7. Finished horseman’s axe.

Prior to insertion, resin was applied at the interface between the handle and the axe head to improve bonding and reduce the likelihood of loosening during use. Then wedges were inserted into the slits. As the handle was driven into the axe head, the wedges were forced into the wood, causing it to expand outward. The combination of resin bonding and mechanical wedging ensured that the handle remained securely fixed.

Following handle insertion, langets, which were fashioned from ¾” x ⅛” mild steel, were installed. They were bent slightly to conform to the shape of the handle and axe head, and were polished to a mirror finish. Brass rivets were used to attach the langets, and they were set in countersunk holes so they could be ground flush with the langets.

After the langets were secured, a brass end cap was installed at the base of the handle. This was done using brass rivets as well. Structurally, the end cap helped prevent damage at the base of the handle during use.

Results

The total length of the axe was 27.18 inches, and the weight was 2.01 lbs [Fig. 7]. The langets were weld stock, the axe head was 4140 alloy steel, the rivets and pins were brass stock, and the handle was white ash. These results fell well within the competition limits of 31.5 inches and 3.3 lbs. This demonstrates that the design successfully met both dimensional and weight constraints.

References

[1] 2026 Competition | Cast in Steel. (2026). Cast in Steel. https://www.castinsteel.net/2026-competition

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[3] Marquench - ThermTech. (2023, November 26). ThermTech. https://www.thermtech.net/marquench/