

SFSA Cast in Steel 2026

Horseman's Axe Technical Report

Tennessee Technological University – Steal Yo Girl's



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Introduction

SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available.

Historical Research

The Pike

The pike or spike emanating from the eye of the axe head is a very common element of many, if not most historical examples. It would be heavily encouraged for historical accuracy, to include in our design. Or if restrictions prevent this, a decorative element emanating from the axe eye should be used. The pike allows the axe to be used somewhat as a spear. There are serious concerns with this being a weak point of our design. In the event of an under strike where this is hit on its side, it would be a likely item to break. (Reference in Appendix A, Figure 1)

Rear Pick

Most examples of horseman's axes from all cultures and periods seen used a spike on the rear of the axe. All these spikes were either straight or had a slight downward curve. All examples except the Hungarian/ polish example use a geometric, square or triangular shape for the spike, with the Hungarian using a round spike that emanates from a decorative bulb.

The Rear Hammer (Scrapped)

Only one highly decorative example was found to include a hammer end. This used a split hammer, creating multiple spikes. This was fairly common in Warhammer construction. Many of these examples are a fun idea to create; however, many of these weapons were not even horseman's axes at all. They were fashioned as a tool to penetrate and damage armor instead of slashing and cutting. (Reference in Appendix A, Figure 2)

Full Metal Handles (Scrapped)

Designs built around a full metal handle are discouraged as they do not utilize our connection with the Tech craft center. Many examples, including the judge's own example, utilize a single piece of steel construction. With the handle being a thin piece of steel. This creates concerns for weight, and casting challenges if expected to be a single piece of construction. (Reference in Appendix A, Figure 3)

Wooden Handles

Wooden handled horseman's axes across all periods and cultures we've seen, used simple straight and thin handles. These are not like the curvy handles used on a modern carpenter's axe but are very basic. Many examples contain reinforcing straps riveted to the handle that span their full length. Combining the strength of steel with wood. (Reference in Appendix A, Figure 4)

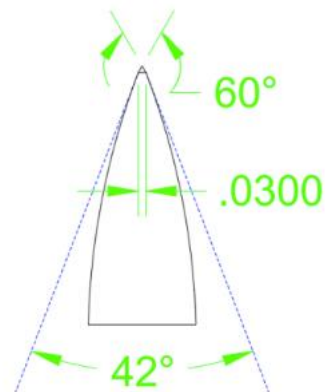
Attachment of Axe Head to Handle

Historical examples often feature single-piece iron construction. Designs incorporating wooden handles typically use a riveted assembly, securing the axe head to the handle while extending rivets along the shaft to anchor an inset reinforcing strap.

In contrast, modern carpenter and woodsman axes commonly use a wedge-fit construction. The handle is shaped to fit tightly within the axe eye, with a slot at the top that accepts a wedge. When driven in, the wedge expands the handle, locking it securely in place. (Reference in Appendix A, Figure 5)

Edge Geometry

The axe edge was not designed for balance or sharpness, but for maximum durability under extreme testing conditions (e.g., repeated impact against sheet metal and other harsh materials). Accordingly, the focus was on edge strength rather than cutting performance. A convex primary bevel was selected, following United States Forest Service guidelines. This geometry is formed using tangent curves between two intersecting 42° lines, increasing thickness behind the edge, and improving resistance to chipping and deformation. Consistent with recommendations from Knife Know-It-All, the design targets a thickness of 0.03in behind the edge, transitioning into a micro-bevel. The micro-bevel exceeds 28° , resulting in a combined edge angle of approximately 60° , comparable to heavy-use chopping tools designed for high-impact applications.



Pike Geometry

Historically the pike typically featured a square cross-section, optimized for armor penetration, with a reinforced base to resist bending or fracture. It was commonly riveted to the axe eye rather than forged integrally and tapered to a sharp point for improved puncturing capability. In our design, the pike adopts a rhombic (diamond) cross-section with unsharpened (false) edges, providing increased lateral strength while maintaining effective penetration. This geometry also aligns with the square cross-section of the rear spike. Due to the absence of definitive data on optimal angles, the design is informed by historical precedents.

Rear Spike Geometry

Specific design data for spike or pick angles is limited, so proportions were derived from the historical examples that informed our overall design. Rather than optimizing a specific angle, emphasis was placed on maintaining proven geometric relationships observed in these references. The spike was designed with a square cross-section and, after sharpening, terminates in a 1/8" square tip rather than a sharp point. This geometry follows United States Forest Service recommendations, balancing durability with effective penetration.

Axe Eye Geometry

The axe eye is the interface between the handle and head, designed as a socket to receive the handle. Among the various geometries available, an oval (elliptical) eye was selected due to its common use in splitting axes and its strong mechanical performance. When properly wedged, this geometry provides a secure, non-rotational fit that maintains alignment between the blade and rear spike. Its elongated axis also distributes impact stresses more evenly, reducing the likelihood of failure at the handle shoulder.

This design, however, requires precise fitment. The handle must be carefully shaped and aligned to avoid imbalance or unsafe use. Additionally, wood shrinkage over time can loosen the fit if not properly wedged, and replacing the handle is more labor-intensive compared to simpler eye geometries.

Handle Design

Due to the loss of our original handle supplier, the plan to fabricate a custom wooden handle was revised to meet project deadlines. Instead, an oversized, pre-made hickory handle was used and fitted to the axe's eye. Final handle length and eye dimensions were maintained as closely as possible to the original pattern design. The

handle was tapered slightly to improve ergonomics, enhance grip, and provide clear front-to-back orientation.

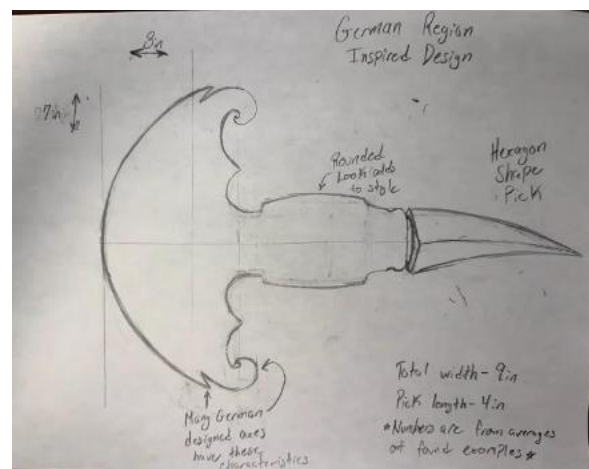
Axe Design Decision

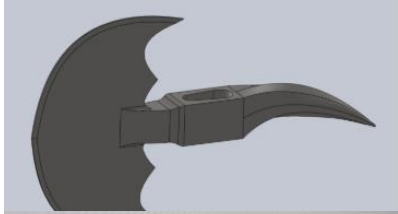
During our team's research of the Horseman's Axe, we all found different designs and styles to each culture that produces each axe. As a team, we struggled to find the design we could all settle on, so we decided to leave it up to democracy. Each member was given the opportunity to make their own design inspired by different cultures. We voted on five different cultures: Spanish, German, Ottoman, Scottish & English, and the design that won was the German Style.

In developing the German-style axe concept, the team evaluated multiple historical examples. A key distinguishing feature identified was the wide, tall axe head, along with the curved geometry of the rear portion. These curved edges reduce the likelihood of the blade binding on rounded surfaces while enabling weapon control techniques, such as trapping and disarming an opponent. Some historically

inspired features were modified to accommodate casting constraints. The pronounced blade curvature was reduced to avoid potential flow issues, and the serrated edge—drawn from modern interpretations—was excluded from the mold design due to its fine detail.

The rear pick design was influenced by geometric forms seen in historical halberds and horseman's axes, combined with the durability considerations of modern pickaxes. A square-oriented cross-section was ultimately selected to balance structural integrity with visual interest, resulting in a design that integrates both historical inspiration and practical performance.





Initial Design- This design was not used as it created many thick portions resulting in shrinkage concerns, and it didn't seem to use the geometric freedom that casting provides.



Final Design - The design was further optimized to improve casting performance and dimensional consistency. Geometry was refined to maintain a more uniform section thickness throughout the part. Concave fillets were added to the rear spike to reduce localized mass and promote directional solidification toward the unavoidable thick sections at the eye transition and the circular base of the spike. The blade size was reduced to better align with historical proportions, and slots for the pike were incorporated to achieve a near net-shape casting and minimize post-processing.

The axe pattern was developed by extending the geometry around the eye to form core prints. A 2%-dimensional offset was applied to account for shrinkage and finishing; however, post-process evaluation suggests that a 3–4% allowance would have been preferable to provide additional material for grinding and refinement.

The model was split into two halves with integrated alignment features, enabling a two-piece pattern. This approach allowed the gating system to be hand-cut in the mold, providing flexibility to iterate on gating design between pours. Both halves were 3D printed in PLA and finished with multiple coats of sandable automotive primer, followed by sanding to achieve a smooth surface. This post-processing step minimized the transfer of print artifacts to the casting, reducing downstream finishing requirements.

Axe Core

A core was used to produce the desired eye geometry and enable vertical internal faces on the axe. We evaluated both shell core sand (heat-activated binder) and no-bake sand (resin-bonded), ultimately selecting shell core sand to minimize gas-related defects and better suit the geometry of the cavity.

The core box was designed as a multi-piece assembly consisting of two identical core print sections, a central section defining the eye geometry, and a cap plate to close the cavity. This segmentation improved manufacturability by simplifying machining of the flat transitions between the prints and the eye. After machining, all components were aligned on a granite surface plate and secured using through bolts. Special thanks to Richard McClain for completing the CNC machining.



For core production, both halves were heated to approximately 600°F in an electric furnace, then aligned and clamped. Shell core sand was introduced, and excess material was immediately dumped to ensure uniform coating, reduce gas generation, and promote complete filling of sharp features.

The core geometry introduced stress concentrations and high friction during removal, leading to breakage risk. To mitigate this, WD-40 was applied to the core box immediately prior to filling. This significantly reduced adhesion and improved core release.

Pike Design

The pike was designed to maintain proportional consistency with the axe head. Its fluting and transitions—from bolster to spear point—mirror those of the rear spike, creating a cohesive overall geometry. Final proportions, including band length and spear point length relative to the handle and axe head, were determined through group evaluation.

To simplify pattern removal and reduce post-processing, the pike was designed with one band in the cope and one in the drag. This enabled flat casting without added draft. However, the long bands introduced challenges, as their surfaces tended to trap loose sand. As a result, mold cleanliness was critical. Despite precautions, many castings exhibited sand inclusions in these regions, exacerbated by the complexity of the required core (discussed in the next section).

The pattern was produced as a two-piece design, consistent with the axe head, which also allowed flexibility to modify the gating strategy between pours. The 3D-printed pattern was finished using sandable automotive primer to improve surface quality.

The pike core had a simple, outward-drafting geometry, allowing the core box to be 3D printed and finished with the same priming and sanding process as the patterns.

Instead of using shell core sand, the box was dusted with parting powder, clamped, and filled by hand with green sand through an opening at one end.

Although dimensionally accurate, these cores were extremely brittle and consistently cracked, even with careful handling. Despite this, they were still usable with cautious assembly. However, the cracked cores frequently caused sand defects at the base of the bands along the pike.

Metallurgy

To approximate 1080/1095 steel, we began with more accessible 1045 steel and targeted a final carbon content of 0.80–0.95%.

Carbon retention during melting was a primary concern, as loss occurs through oxidation. To minimize oxygen exposure, we selected an induction furnace over fueled furnaces (propane or coal), which require forced air inputs. Although no flux was used, slag was intentionally retained on the surface to act as an oxygen barrier. Temperature was also controlled, as higher temperatures accelerate both carbon loss and reuptake; melts were conducted at 3300°F to balance fluidity and carburization.

For carburization, we evaluated graphite and charcoal. While graphite offers superior purity and reuptake efficiency, it was unavailable, so lump charcoal was used. Based on literature values (~75–80% efficiency) and process limitations, we conservatively estimated 40–50% carbon reuptake, assuming ~75% fixed carbon in the charcoal.

Following casting, gating sections were normalized, quenched, and tempered. Resulting hardness values aligned with those expected for 1080 steel, providing confidence in composition despite the absence of spectroscopy or XRF verification.

After confirming our material behaved similarly to 1080 steel during heat treatment, we followed a standard 1080 process. Both the axe and pike were fully annealed at 1500°F with a controlled cooling rate of 25°F every 30 minutes. After grinding and polishing in the softened state, the pieces were normalized by air cooling from 1600°F. They were then austenitized at 1450°F, oil quenched, and tempered at 500°F for 10 minutes. This process achieved a final hardness near our target of 55 HRC.

Nondestructive Testing

Nondestructive testing efforts began with a broad evaluation of available methods to assess internal and surface integrity. X-ray imaging was initially considered for internal

defect analysis; however, limited access to suitable equipment made it impractical. As a result, the testing plan was refined to include hardness testing, dye penetrant inspection, and microstructural analysis, all of which were achievable within the project timeline.

Dye penetrant testing was used to identify and characterize surface defects, including crack depth, severity, and distribution within the cast axe heads and pikes. (Reference in Appendix B, Figure 1)

Hardness Testing

Hardness testing was conducted using a Rockwell hardness tester on representative samples taken from the gating system, which were normalized, quenched, and tempered. These samples were selected to reflect the processing conditions of the final cast components. The measured hardness values were consistent with those expected for 1080 steel.

Microstructure Analysis

Microstructural analysis was conducted in collaboration with the engineering department using on-campus metallography facilities. Samples were taken from the gating system and were only quenched. Sectioning was performed with a diamond-impregnated copper wheel, followed by mounting (Buehler SimpliMet 4000) and polishing (Buehler EcoMet 30). During preparation, rapid surface oxidation was observed, requiring careful moisture control and thorough cleaning to preserve surface quality.

While available imaging capabilities did not allow for precise carbon quantification, a qualitative comparison to reference microstructures was performed. The samples exhibited well-developed pearlitic structures with minimal ferrite presence, supporting an estimated composition exceeding 1070 steel and indicating successful heat treatment response. (Reference in Appendix B, Figure 2)

Post Processing Pike

The pike exhibited significant cracking at the base of the spike, requiring corrective repair (Reference in Appendix B, Figure 3). The cracks were removed through grinding, followed by surface cleaning and rough shaping. To prevent thermal shock and additional cracking, the pike was preheated to 600°F prior to welding. Cracks were then filled using TIG welding with a mild steel filler rod, performed over two controlled heat cycles to ensure adequate penetration and shielding.

Post-repair inspection using dye penetrant confirmed strong weld integrity and crack closure, with only a single minor surface-level indication remaining. This defect was deemed non-critical and was removed during final finishing.

Axe Head & Handle Attachment

To secure the axe head, we implemented a **cross-wedge system** within the eye—an approach commonly used in handcrafted axes for maximum stability. This design forces the wood outward in four directions, creating a tighter mechanical lock between the handle and the head. We cut slots in a cross pattern and installed three wedges (two longitudinal and one perpendicular), which were both glued and hammered into place to ensure a firm fit.

Attaching the pike to the top of the axe proved significantly more challenging. Our initial design called for two to three rivets along the metal bands; however, due to alignment difficulties. The round geometry of the handle provided no consistent reference angle, making it difficult to achieve a perfectly perpendicular drill path. To minimize error, we drilled through both the pike bands and the handle simultaneously. Attempting additional rivets would have likely introduced further misalignment and risked weakening the structure, so we intentionally limited the design to a single, well-executed connection point. For fastening, we used ¼-inch bronze rod, cut into short sections and hammered on both ends to form secure rivet heads.

Overall, the system functions as a **“belt-and-suspenders” approach**: the cross wedge provides the primary structural integrity, while the rivet serves as a secondary retention feature to prevent movement and maintain alignment.

Final Measurements

Length: 26". Width: 9", Weight: 4lbs 12oz

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Appendix A

Figure 1:



Figure 2:



Figure 3:



Figure 4:



Figure 5:

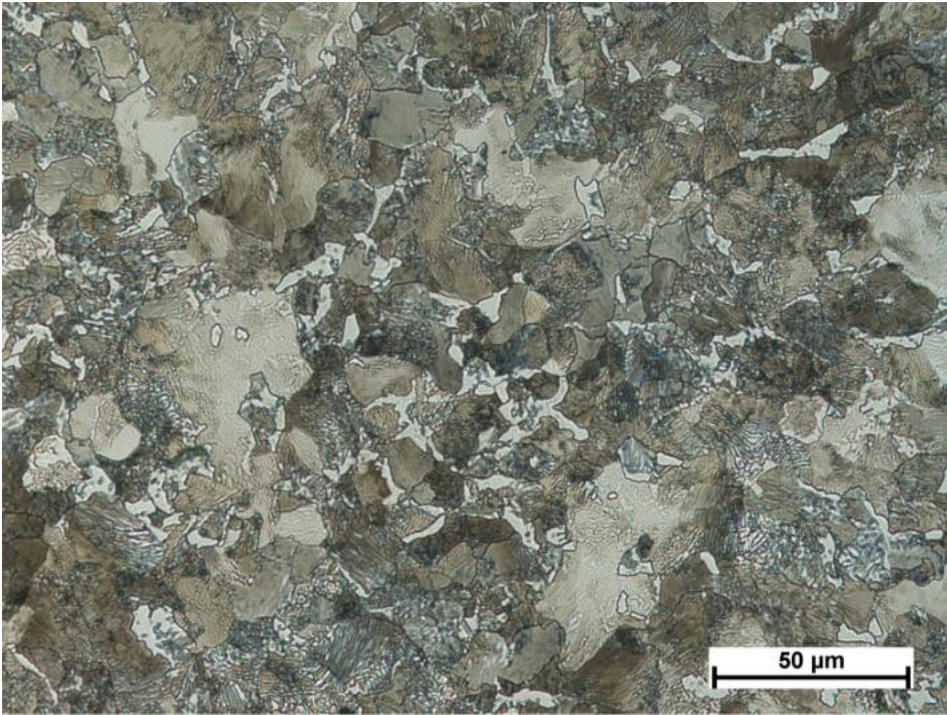
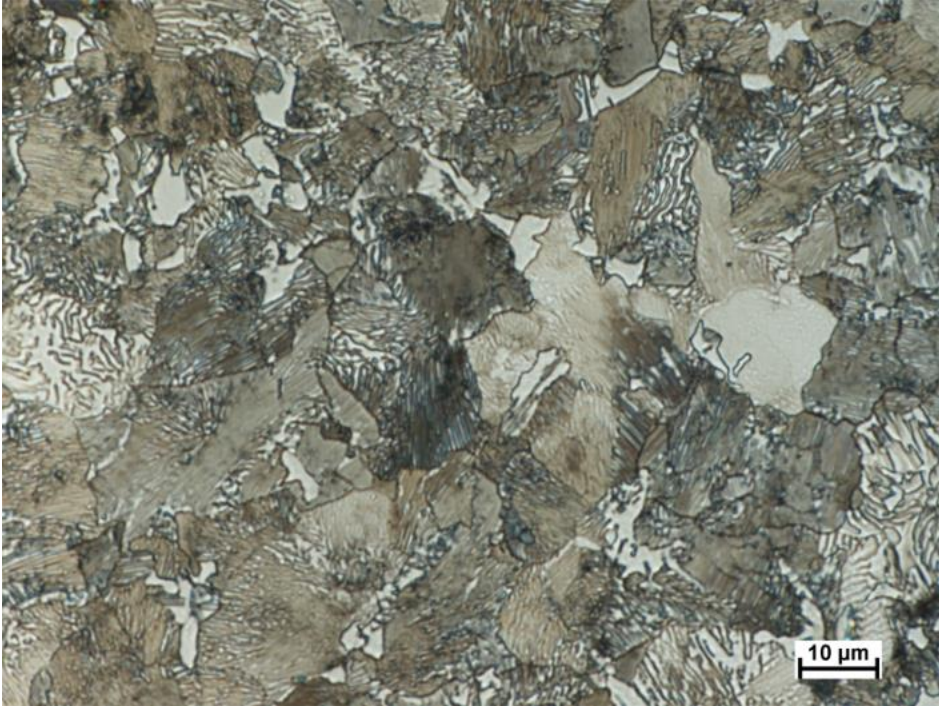


Appendix B

Figure 1:



Figure 2:



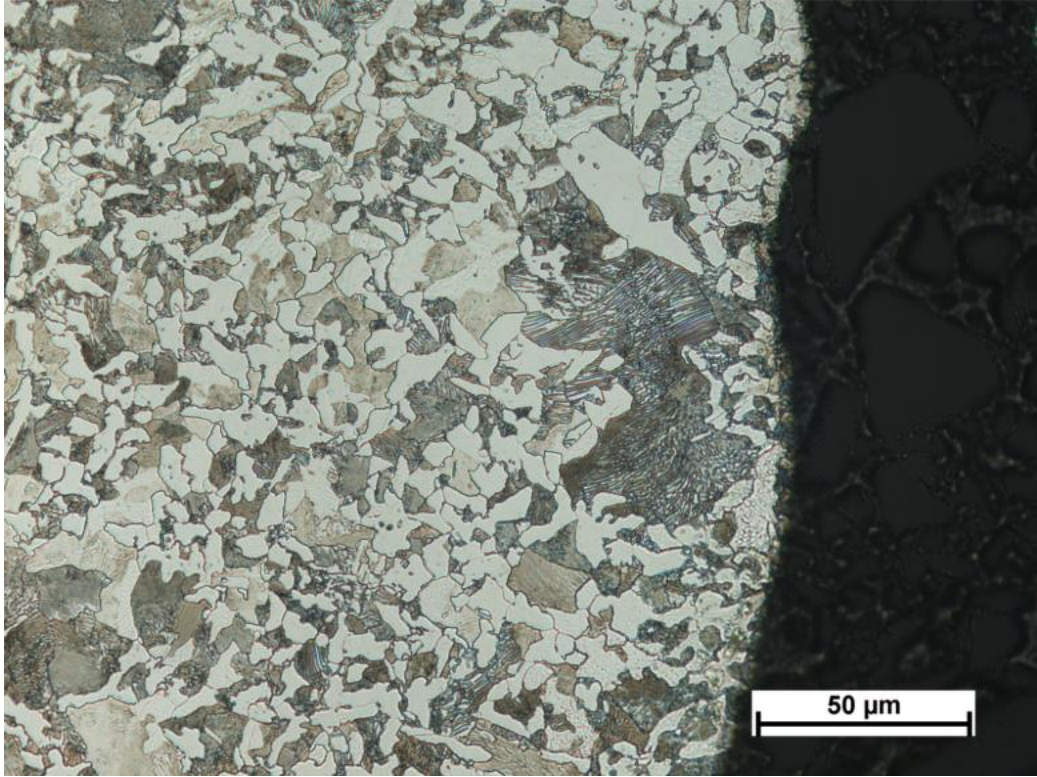


Figure 3:

