

SFSA Cast In Steel 2026 – Horseman's Axe

Technical Report

Missouri University of Science and Technology – Foundry Inspectors



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Introduction

The Foundry Inspectors is a team formed of Missouri University of Science and Technology students to partake in the 2026 Cast in Steel competition. SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. This team is a textbook example of how that goal has come to fruition. Cast in Steel was also a wonderful reason to experiment with technology usually reserved for research at the university.

The team was given the freedom to make their own decisions, mistakes, goals, and their own horseman's axe. Missouri S&T has exceptionally knowledgeable faculty that are always willing to help their students succeed. Any time the team needed advice, fact checking, or guidance there was someone there to help. However, the students were able to use the full extent of their education and experience to fly solo in most aspects of the project. The Foundry Inspectors are proud to say that the heat procedure, melting, casting, heat treatment and construction of the axe was completely student led with small suggestions being made by faculty along the way.

S&T's V.H McNutt Hall is home to the Robert V. Wolf foundry, which made it possible for the team to forgo an industry sponsor and cast the axe as a standalone team with their own practices. This was another great learning example as steel heats are more demanding than aluminum or bronze, which is what students are usually exposed to. This paper contains the reasoning behind the axe design, alloy selection, casting techniques and heat treatment of the horseman's axe dubbed "Tank."

Design Process and steps to the Final Product

Two members of the Foundry Inspectors cast in steel team are graduating seniors, one is a graduate student, and one is a sophomore, leading to a diverse team with different experiences and skill sets. The team decided that this competition would be a learning experience while having fun while focusing on a semester of demanding coursework and projects. When first drafting the initial design for Tank, it was realized that the team all plays Magic: The Gathering, a popular card game, and some of the cards have iconic art featuring axes. One such card is Lone Rider with art by Daarken. In addition to this, inspiration was taken from real world axes such as a replica made by Wulflund and a reference image from an arms and armor forum. Images of these axes are included in the appendix as Figures 1-3 in appendix A. The ideas taken from these references include the geometry of the spike, the asymmetry of the top and bottom hooks or curves of the blade,

the cutout, and the aesthetics of the inverted scallop edge. The remaining elements such as the eye and curve of the blade were chosen for cohesiveness and structure.

The axe was modeled in Autodesk Inventor, where a sketch was converted to a 3d model various cuts and extrusions. Three distinct iterations lead to the final design as seen in Figures 4-6 in Appendix A. Changes were made to the design to bring more safety to the user, increase symmetry and aesthetics, and increase structural integrity in that order. Minor changes were made periodically for weight reduction during the development process. Changes were recommended and approved by the team as a group effort, but the weight of the cast axe was greater than estimated. It is unclear where the discrepancy happened, but Tank was living up to their name as a heavy hand axe weighing 3.3 lbs for the standalone axe head. This forced the team to cut off some of the spike and remove some material around the eye of the axe.

The mold for this axe was created using an ExOne S-Print sand mold 3D printer that is commonly used in the Robert V. Wolf foundry. The mold consisted of a cope, drag, and two cores, one for the eye, and one for the cutout in the blade. A CAD model for the mold can be seen in Figure 7 in Appendix A. The mold gating system was a simple riser through the sprue that fed into the axe. This system leads to a simple horizontally parted mold that can be mass produced if needed for an undead army or whatever dubious plans the team may pursue in the future. Four sand molds were printed and cleaned of excess sand before being glued together. The molds were then set out on the pouring floor with weights on them to prevent separation along the horizontal parting line due to hydrostatic pressure. Molding the exact axe shape with the sand printer was convenient; however, there were drawbacks to this method such as the surface quality of the axe. The 3D printed sand mold has a stepped surface of the inner mold cavity due to the print layers, in combination with relatively high pouring superheat for fluidity, resulted in sand being washed or entrained into the surface of the casting. This sand entrainment could have been avoided by using a mold wash on the sand mold to cover the rough surface in future castings. Thankfully, the team had planned to grind the axe to a clean surface to provide a clean final product.

An investment shell of the axe was made as well for greater dimensional accuracy and surface finish but, unfortunately, it cracked during filament burn out. The model of the axe was 3D printed with PolyCast filament, and a foam and hot glue sprue was attached. The model was dipped in a ceramic slurry and sprinkled with silica sand for a total of seven layers plus one additional slurry dip at the start and end for a sealing layer. Once the layers were dry the mold was put in a kiln to burn out the investment model at 1000 °C. The investment shell process was new to the team, and it was enlightening to learn the process of how investment shells are made.

The Foundry Inspectors axe was cast out of AF9628 steel, which is a high-performance grade steel developed by the U.S. Air Force. It is a high-strength, low alloy steel alloy that was chosen for its high hardness, with an exceptional balance of strength and toughness. The alloy is also relatively inexpensive to produce for the team, due to recycled scrap being similar to the nominal chemistry of AF9628. Heat treatment was performed according to the work performed by Cardoso et al. [1] The heat treatment consisted of austenitizing at 1100 °C for one hour wrapped in 2 layers of 309 stainless steel foil. Graphite and carbon steel machining chips were spread between the two stainless steel foil layers to create a sacrificial barrier for the axe to avoid decarburization. After the axe was removed from the furnace, a 35 °C water quench was performed to produce a martensitic matrix in the axe blade and spike. The axe was then tempered at 175 °C to precipitate a metastable ϵ -carbide, which is the key to the strength and toughness combination of this composition. The team was able to avoid quench cracking of the complex shape of the axe head through this heat treatment even with agitated water quenching.

An additional design challenge the team imposed on themselves was making an axe primarily out of scrap cast material found around the foundry. Using chemistry data from a spark optical emission spectrometer (OES), each scrap casting was measured for its composition, incorporated into a charge calculator until the target chemistry matched the composition of AF9628. A minor amount of trim additions and deoxidizers were used to achieve the final target chemistry which can be found in Appendix B.

Experimental Procedure

The axes were inspected after casting, and the best of the four cast was chosen as the team's champion. Pictures of cast axes and inspection findings are in Appendix A as Figures 7-9. There was a slight cold shut on the casting but only in sections that would later be ground down. There was also a small amount of sand penetration, particularly around the cutout in the blade, especially in corners of the casting where the temperature is highest and the binder can degrade while the steel is still solidifying. Overall, the axe heads turned out as a sound and solid castings. There was flashing at parting lines along the blade edge and around the cores. These were subsequently ground off in post processing. OES analysis shows the final composition to be suitable for AF9628 ranges as seen in Table 1. The team did not intend to reduce the volume around the eye, but it produced a nice porosity-free cross section in the axe as seen in Figure 10. However, a small amount of porosity was present in the axe blade as it was ground down, but these pinholes were ground away to make a solid edge. A revised mold design could include a second riser to feed the blade section of the axe and mitigate the risk of porosity in the blade.

Table 1: Comparison of Casting Composition and Nominal AF96 Composition [2]

Nominal and Final Casting Composition									
Wt%	Fe	C	Si	Mn	Cr	Mo	Ni	Al	V
Casting	91.02	0.30	0.67	0.88	2.68	1.13	3.04	0.03	0.25
Nominal	Bal.	0.28-0.32	> 1.25	> 1	2.5-3	1-1.2	>3	> 0.15	0.25-0.35

Results and Conclusion

The final assembly consists of an AF9628 steel axe head mounted on a hickory dowel with a final weight of 3lbs and a length of 30 inches. The team did not have enough free time for in-depth mechanical testing and metallography due to classwork, senior design projects, and research. However, based on literature, the axe is expected to have a hardness of 50 HRC and a Charpy impact toughness of 35 J at -40 °C. Tank was designed as a simple and practical axe that prioritizes function over form. Using this philosophy, we present Tank, an indestructible horseman's axe that won't fail, no matter how many times the handle needs to be replaced, solving the Axe of Theseus paradox

Appendix A – Axe Design

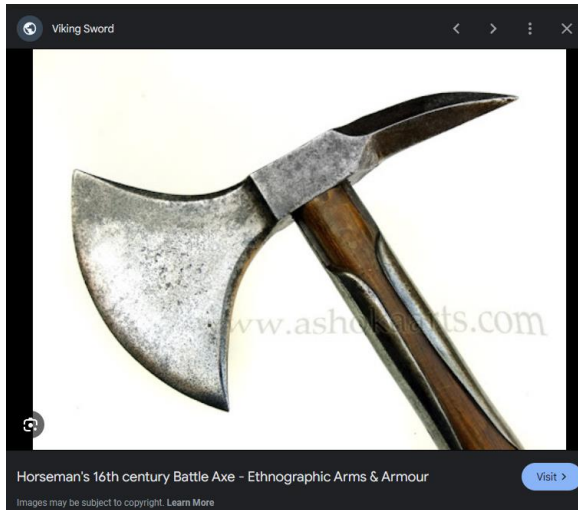


Figure 1 Image of horseman's axe posted as reference for a forum discussion. <http://www.vikingsword.com/vb/showthread.php?t=16469>

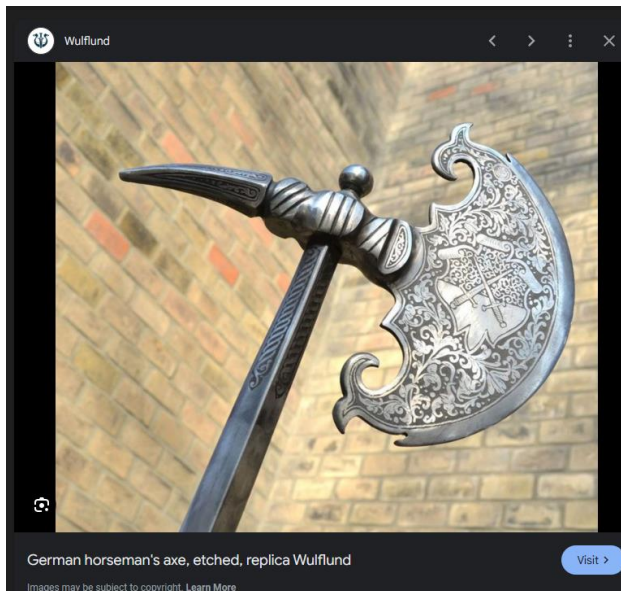


Figure 2 Replica of German Horseman's axe produced by Wulflund. <https://www.wulflund.com/weapons/axes-poleweapons/german-horseman-s-axe-etched-replica.html/>



Figure 3 a) Lone Rider MTG card, b) the same card zoomed in.

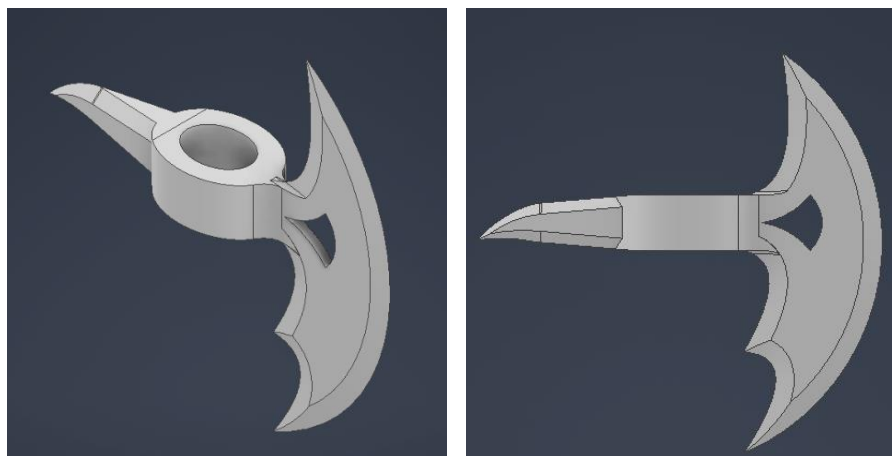


Figure 4 Isometric and side views of original axe model in Inventor.

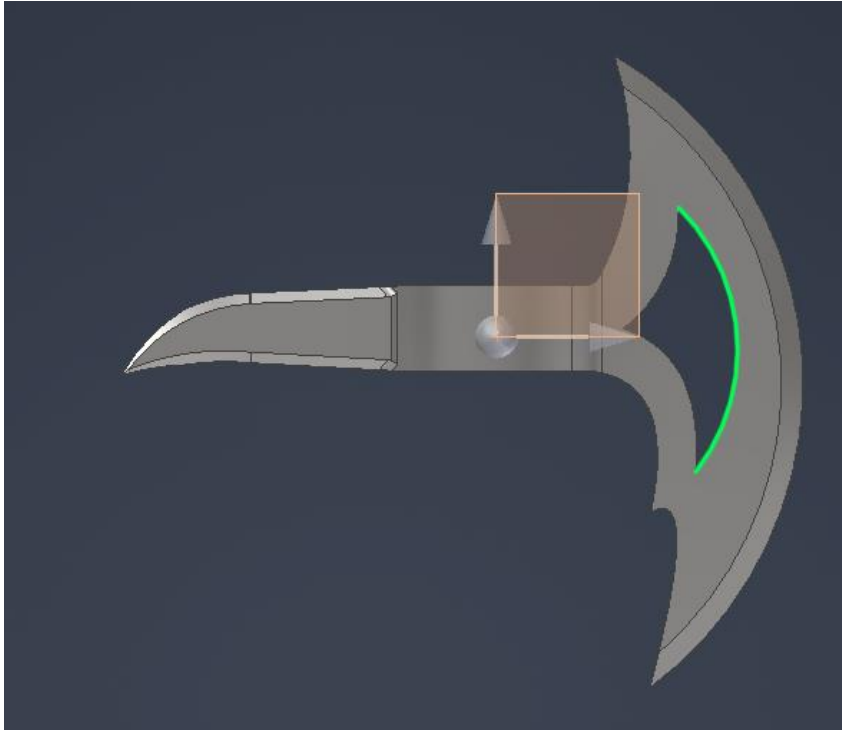


Figure 5 Side view of axe design, second version.



Figure 6 Side view of third and final version of the axe.

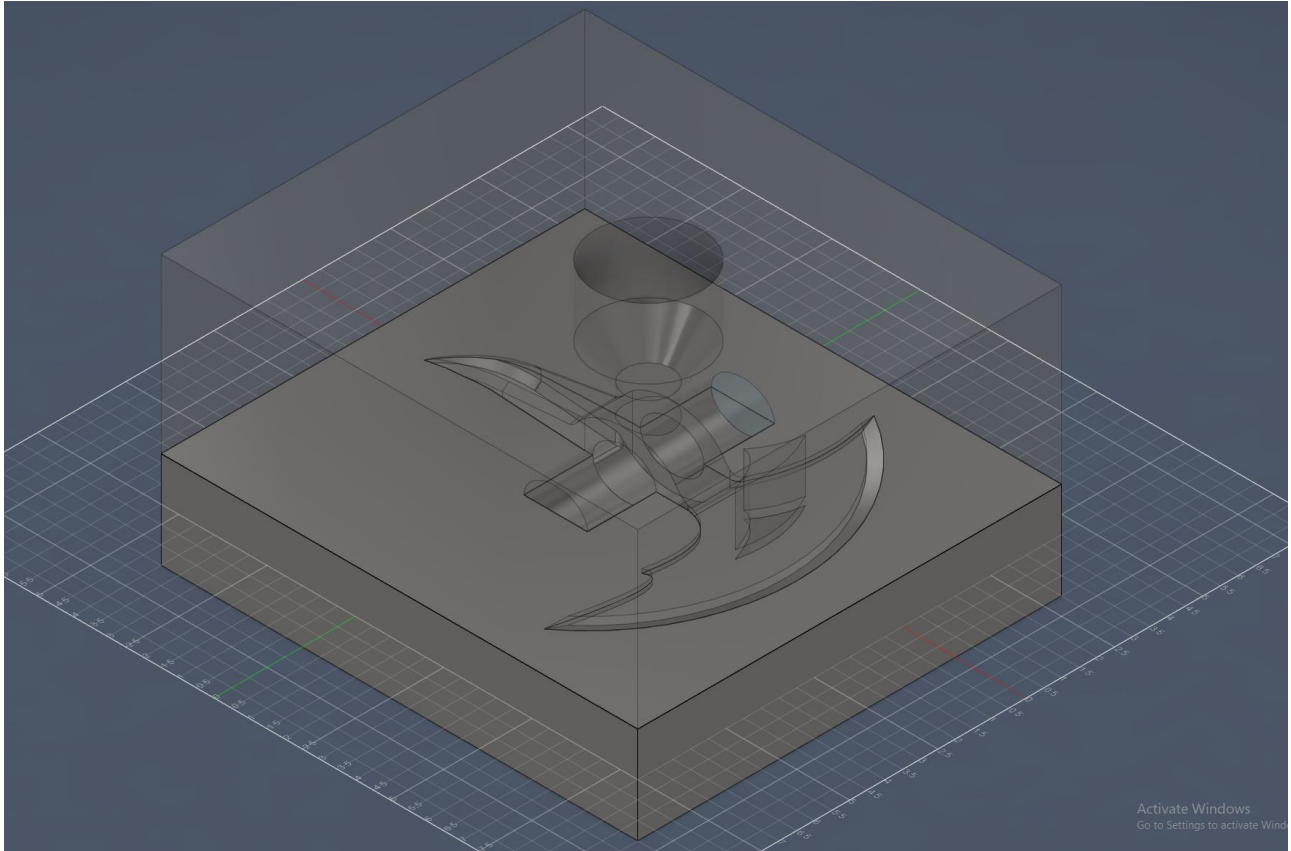


Figure 7 The 3d model of Tank's mold including space for two cores and a simple riser included in the sprue.



Figure 8 Sand penetration near axe blade cut-out.



Figure 9 A cold shut on the face of the axe blade.



Figure 10 Sand penetration on axe spike.



Figure 11 A cross section of the axe eye, cut to reduce weight on the axe.

Appendix B – Heat Procedure

Heat Procedure

HEAT 1: 3/5/2026

Foundry Inspectors Cast in Steel

Goal

Casting of Horseman's Axe and a small Y block mold for mechanical testing and heat treatment

Safety Plan

All participants will wear appropriate PPE for their roles as defined in our foundry safety guidelines and the list below. This includes minimum safety glasses and a flame-retardant jacket regardless of role.

For individuals near the pouring floor a list of PPE is below:

- Safety glasses
- Long sleeve fire retardant jacket
- Full length cotton or fire-retardant pants
- Steel toe boots

For individuals conducting work on the pouring floor while furnace is uncovered or pouring is in process, the only exception is the crane operator as these individuals need full use of hands and ears to operate equipment safely:

- Safety glasses
- Long sleeve fire retardant jacket
- Full length cotton or fire-retardant pants
- Steel toe boots
- Aluminized Goggles
- Aluminized jacket
- Aluminized gloves (with exception of crane operator)
- Helmet with shaded visor (with exception of crane operator)
- Thick mitten over gloves for individual manipulating investment molds

If a breakout occurs or significant loss of liquid metal containment occurs, an individual will be on standby with a bucket of sand to toss onto metal.

In the event of a fire, all individuals will evacuate building unless the fire is deemed manageable at which point fire extinguishers are on standby and ready to be used. Once fire is out, all individuals will evacuate foundry.

Target chemistry

C	Si	S	Mn	P	V	Cr	Al	Mg	Mo	Ni
0.32	0.8	0.003	0.9	0.005	0.35	3	0.05	0.005	1.50	3

1. Charge material.

In charge	Weight (kg)	Weight (lbs)
Blocks	36.4	80.25
Fe75Si	.3	0.661
Desulco 9001		
Graphite	0.045	0.099
ferromoly	0.7	1.543
FeV	0.17	0.375
Metallic Cr	1	2.205
Ni Shot	0.95	2.094
Al Shot	0.01	0.022
Total melt		
	39.35	86.74

2. Molds

- 4: 3d sand printed axe molds
- 1: Single investment shell axe head
- 1: No bake small Y-Block mold
- 2: green sand pig molds

3. Liquidus calculation

Liquidus temperature calculated by JMat Pro:

- 1450 C liquidus.
- 1620 C super heat

Preparation before the heat

- 1) Prepare 2 green sand pig molds.
- 2) Check argon tanks level.
- 3) Prepare 3 stir rods
- 4) Have vermiculite baked ready.
- 5) Cut and weigh up charge material.
- 6) Bake charge material to remove contaminants.
- 7) Lay out temperature probes
- 8) Preheat investment mold to 1000C in kiln.
- 9) Review procedures with the pouring team.
- 10) Personnel – main heat
 - Evan: furnace, alloy additions, furnace crane.
 - Ben H: video.
 - Savannah: temperature probe, ladle crane, kiln lid.
 - Ben R: ladle support
 - Will Kirk: ladle wheel, puck and vacuum samples, hand ladle.
 - Will B: Investment Shell removal from furnace, Scraping

4. Melting and pouring procedure

Main heat

- 1) Stack charge in crucible and preheat excess induction iron in nearby furnace to 800C.
 - a. Metallic Chrome
 - b. Stacked armor blocks
- 2) Begin heating up Induction Furnace at 12:00 P.M. 3/5/2026.
- 3) Ramp furnace until the material is liquid.
 - a. 15kW for 30mins
 - b. 20kW for 10 mins (begin Preheating ladle)
 - c. 25kW for 10 mins (add argon line)

- d. 30kW for 10 mins (1hr total ramp)
 - e. 35kW to desired temperature
- 4) Add additional blocks in until fully liquid
- 5) Add alloying additions.
 - a. FeMo
 - b. FeV
 - c. Half FeSi
 - d. Graphite
 - e. Other half FeSi
- 6) Once alloys are mixed in Raise temperature to superheat for pouring: 1620 C
- 7) Deslag using vermiculite prior to pouring if necessary.
- 8) Remove the investment axe head mold and place it on sand and fixture.
- 9) Furnace off
- 10) Pour steel into Hand ladle.
 - a. Adding 2-3 Al shot while pouring into ladle
- 11) Turn the furnace back on to 35kW.
- 12) Heat back to 1620C
- 13) Move ladle in front of 100lbs induction Furnace.
- 14) Shut off the furnace and fill the ladle.
 - a. Add remaining Al into the stream during tap
 - b. Add more if necessary (if the ladle is a sparkler)
- 15) Move ladle to each 3d printed axe head mold and pour into them.
- 16) Once the axe mold is full, pour the rest of the material into a small Y-Block mold.
- 17) Excess material if any is to pig out.
- 18) Cover molds with Kao-wool.

Resources

[1] R. A. Cardoso, “Effect of Thermomechanical Processing and Heat Treatment on the Microstructure and Mechanical Properties of Ultra-High Strength Steels,” Ph.D. dissertation, Missouri Univ. of Science and Technology, Rolla, MO, USA, 2024.

[2] Carpenter Technology, “AF-9628,” *Carpenter Technology Alloy Finder*. Accessed: Mar. 26, 2026. [Online]. Available: <https://www.carpentertechnology.com/alloy-finder/af-9628>

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