SFSA Cast In Steel 2026 – Horseman's Axe Technical Report

Youngstown State University – Steel Tuxedos

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1. 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. This year's goal of creating a horseman's axe via casting presents multiple unique challenges that The Steel Tuxedos have tackled using technologies and techniques refined from previous projects. Our unique use of 3D printed sand molds with draining gating systems, as well as simulation technology, allowed us to cast a complete horseman's axe in one pour with minimal clean-up and post processing.

Early in the design process, the team researched historical horseman's axes and noted the variety in blade geometries and chose a design that maximizes strength, while remaining true to historic axes. The axe was designed with functionality in mind and features a long front blade that comes to a point at the top for stabbing, as well as a spike on the backside for piercing armor. The handle is indexed to promote a rapid, repeatable grip for the user.

Material selection was one of the most significant variables in the creation of this model, with hardness and toughness needing to be balanced in accordance with the function of the axe. Historical axes had metal handles - our team chose to replicate this and cast the handle and head as one piece. A2 tool steel can withstand the forces exerted on the axe during strikes, while having enough toughness to not roll the blade edge or spike.

The mold was not traditional; our team designed a gating system with a draining riser. MAGMAsoft was used for mold design and to estimate the drain time. The mold components were 3D printed sand as the mold geometry was not possible with traditional rammed sand methods.

2. Product Overview

Our axe shares features seen on historical horseman's axes, including a straight spike on the back of the blade, rondels around the grip, and a metal handle. Much like traditional horseman's axes, our axe also features an overall length that is short enough to be easily wielded with one hand, allowing for better maneuverability and making it exceptional in close-quarters combat. The axe is cast with the head and handle as one piece to improve strength. It is made of A2 tool steel for its balanced hardness and toughness.

Final Height: 17.75 inches

Final Weight: 2.8 lbs

3. Design Methodology

Preliminary designs for the axe involved a head made of steel with an overmolded handle made of magnesium. This was desired for weight purposes but was scrapped due to concerns surrounding the heat treat compatibility of the two materials and the strength required from the magnesium. Ultimately, the axe was cast with head and handle as one piece of steel. This design increases strength and simplifies the manufacturing process. While modern handles are made of wood in order to reduce weight, our team elected to cast the handle along with the axe head to emulate traditional forged axes. To maximize geometrical strength, the axe neck's cross section is longer than it is wide. This reduces overall weight and resists deformation during strikes.

The axe head was designed with functionality in mind. The blade has a cutoff on the bottom end for weight reduction and aesthetics, while the top is pointed to serve well in thrusts. A tailspike is oriented perpendicular to the axe handle extending opposite the blade so that the spike is aligned with the force of a rear-ward strike. Historical axes feature spikes on the rear of the circular blade so another strike can be made without resetting from a swing.

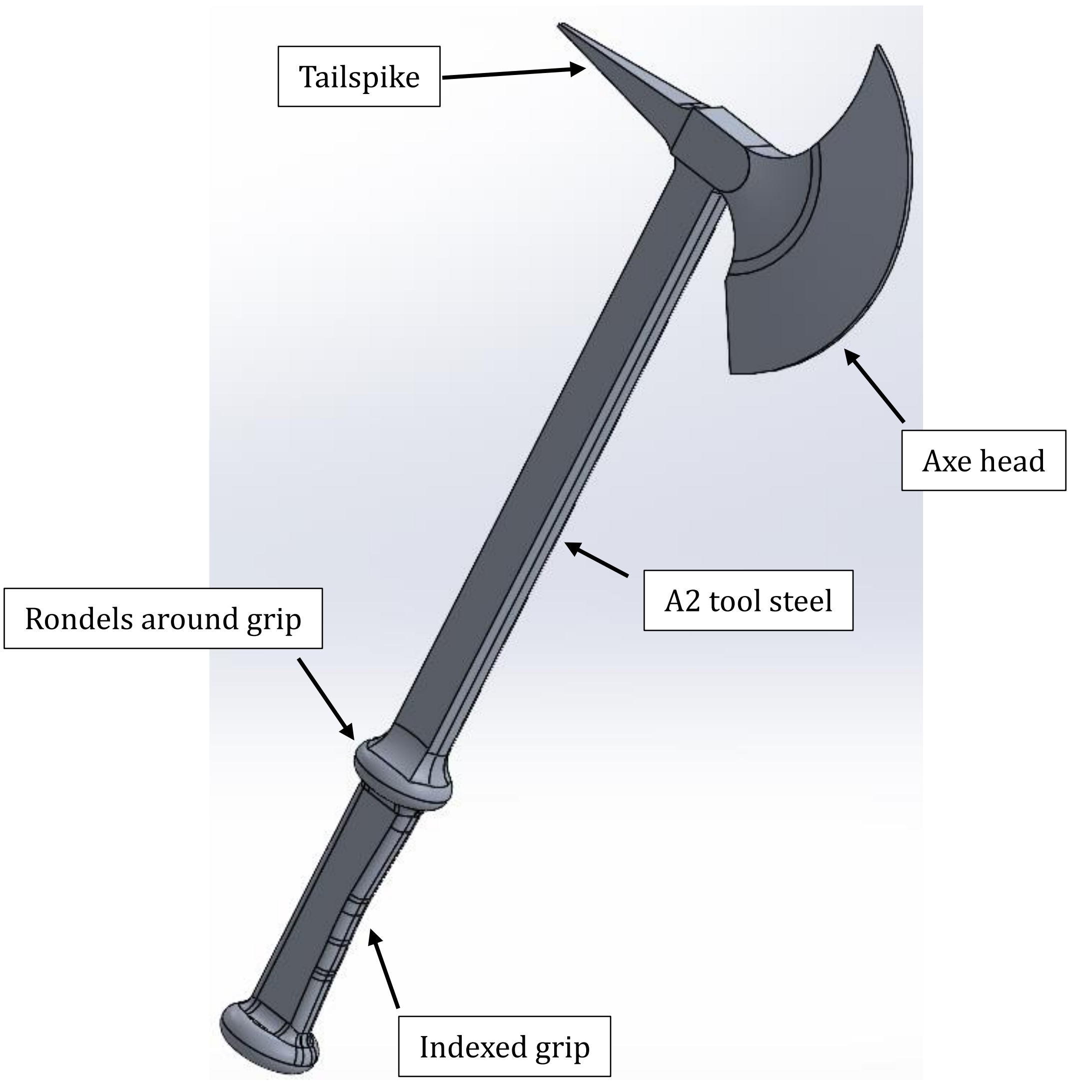

Figure 1: Axe model in SolidWorks

4. Mold Design and Gating System

It was decided early on to use a binder jet sand mold for the casting, commonly referred to as a 3D Sand Printed Mold (3DSP Mold). 3DSP molds allow for reproducible and repeatable geometries that are not possible with other methods. This technology is available to Youngstown State University through a partnership with Humtown Products. The university also has access to MAGMAsoft, a powerful tool for simulation of the casting process.

Our axe design lends itself to a monolithic pour, where the entire axe is cast at once. This presents a problem with the riser since it can cause hot tears in the casting because of the difference in mass from the cast part. We also wanted the solidification to start from the axe head, specifically the edge, and progress down the length of handle. We were able to solve this problem because of the ability of 3DSP molds to construct complex and precise mold geometries repeatably. We designed a 3DSP mold with a valve system that allows the draining of the riser when feeding is complete. This has the added benefit of eliminating the bulk of the gating and risers, significantly reducing post-processing work.

The solidification was controlled by varying the mold wall thickness. Thinner walls lead to higher thermal flux and therefore faster cooling. Thinner walls were located at the blade edge so that solidification started there and then progressed along the length of the handle. This solidification direction was also supported by locating gates along the handle to supply material and heat. The axe cavities were oriented with the blade edge at the bottom so gravity would feed metal into the thin section.

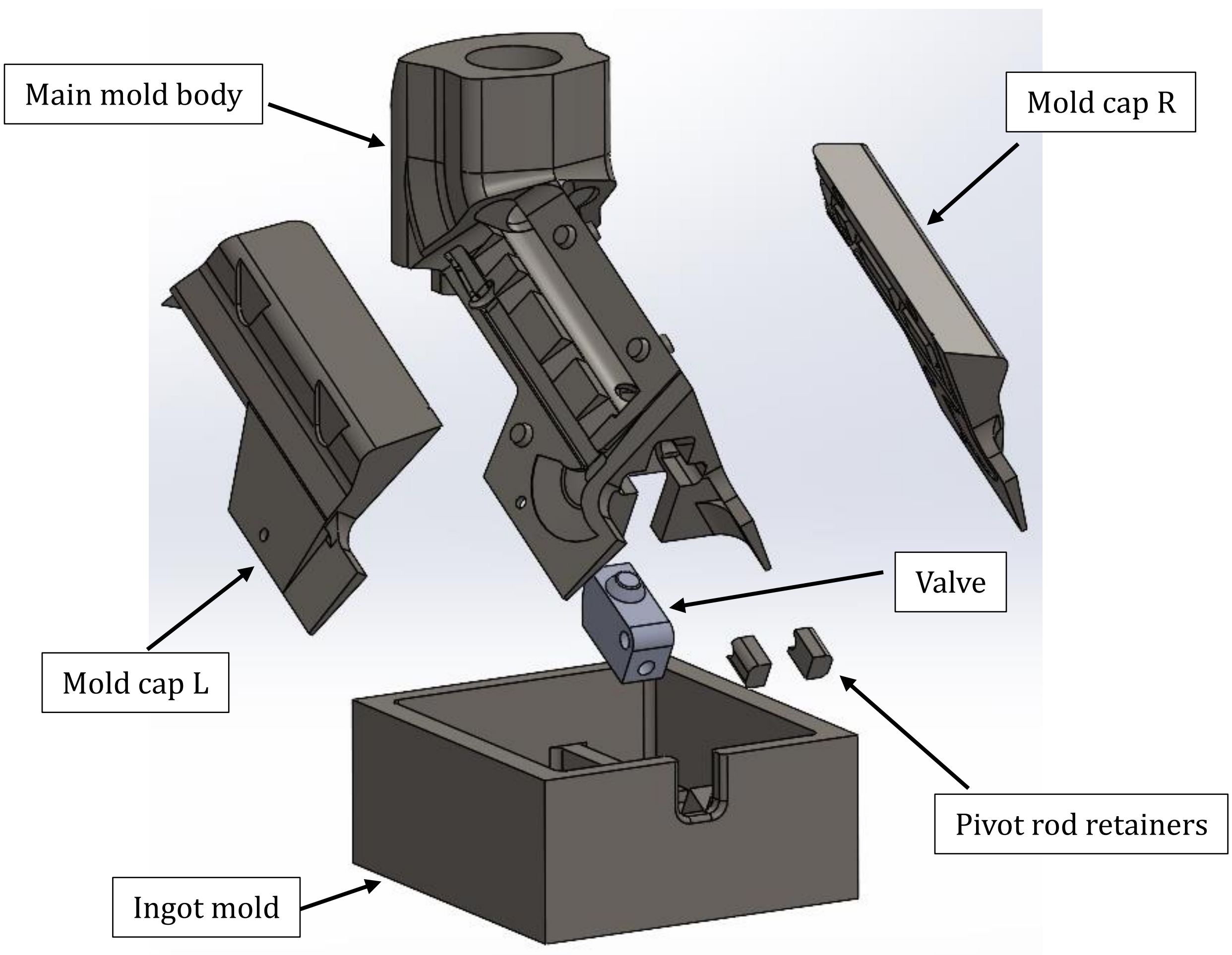

Figure 2: Exploded view of sand components

5. Casting Process

The mold consists of seven 3DSP components. One main body piece with a valved drain on the bottom end is held between two mirrored mold caps on the sides. A steel pivot rod is inserted through the valve and seated underneath the drain. Two retainers are placed in front of the pivot rod to keep it in place. This assembly sits inside an ingot mold so the drained material is ready for easy re-melt. The back end is supported by two cinderblocks which reduces the amount of printed sand. The valve handle is a metal rod that slides through the valve and a matching hole in the main mold body to lock the drain closed and prevent unwanted activation. The valve discharge is shrouded by the mold for safety of the valve operator. The mold assembly is secured by two C-clamps around the top, a bolt/nut/washer set on the bottom flange below the blades, and glue between mating surfaces.

Figure 3: Assembled molds - front view

Figure 4: Assembled molds – side view

Figure 5: Assembled molds: rear/top view

Draining the riser at the correct time is crucial to the success of the mold technique. Using MAGMAsoft, the simulation can provide insight to the solidification progress so that part feeding is complete and the riser is no longer necessary and can be drained. After examining the simulation results, we concluded a drain time of 45-50 seconds after pour start would yield the most favorable results.

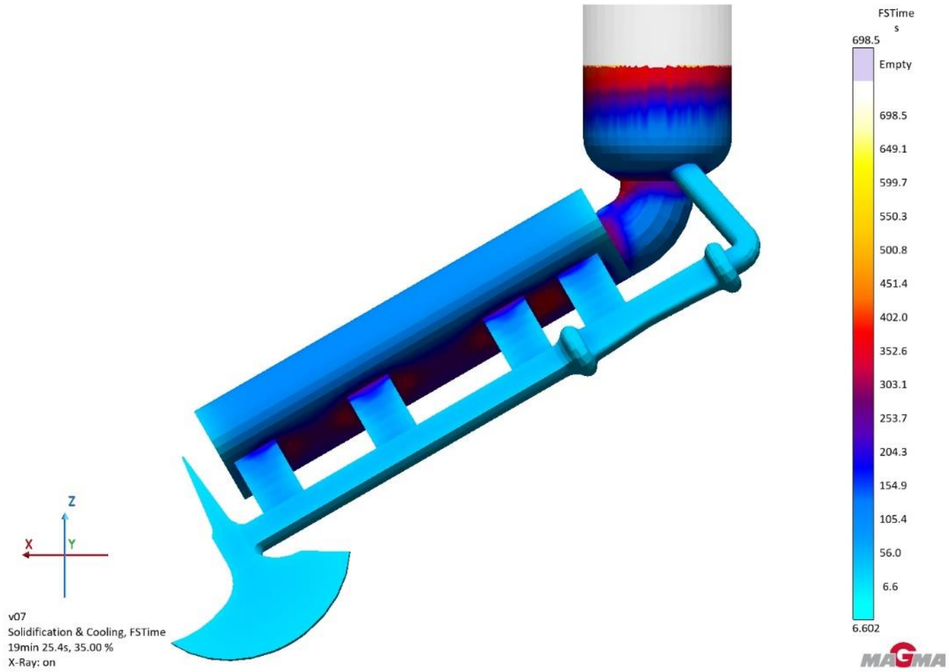

Figure 6: Fraction solid simulation results. Used to determine drain time.

The pour was performed at Trumbull Metal Specialties in Niles, OH. The team prepared and assembled three molds. The furnace was tapped once for the first two molds and once again for the third. Each tap was at ~3000°F to reach a target pour temperature of ~2970°F.

The first mold was not glued, only clamped and bolted together. Metal leaked out of the seams in the pour leading to unfilled handles. This mold was to be drained at 55 seconds, and due to the leaking mold and the longer wait time, the drain was unsuccessful. Breakout revealed our axe heads to be totally filled despite the defects in the handles. Two of the ingots from the mold were fused together, with one ingot as the intended shape.

The second mold was glued, clamped and bolted and to be drained at 50 seconds. It successfully produced three ingots and two fully formed axes.

The third mold was glued, clamped and bolted and intended to be drained at 55 seconds. The clamping force applied to the sides of the mold caps was greater than necessary, causing stress in the already thin layer of sand. The mold thickness was designed thinner to allow for quicker cooling of the axes, but the heat from the steel was too high for the binding agent during solidification. An aluminum pour temperature would have been appropriate for the mold thickness.

6. Post-Cast Processing

We aimed to minimize post-processing work during the design phase. Once casting was complete, the remaining gating was cut off. This material was cut away using 4-inch angle grinders fitted with abrasive cutting wheels. For any thicker leftover steel, we switched to hard abrasive grinding disks until we achieved the desired reduction. We then smoothed down flashes, burrs, or protrusions using sand abrasive flapper wheels, progressing through grits of 40, 60, 80, and 120 for a fine finish before moving to the next stage. The axes were polished with a rotary abrasive polisher at 120 grit and subsequently heat treated. After heat treatment, we sandblasted the axes and brought them back to our studio for sharpening with the Houseware HW belt sander and additional touch up polishing. Lastly, the handles were wrapped with adhesive grip tape to improve grip comfort and reduce vibration transfer.

7. Heat Treatment

The selection of A2 Tool steel was influenced by the ease of the heat treatment process. Air cooling made the process faster and easier. All stages of the heat treatment were done on campus using a Nabertherm GmbH induction furnace. The process was planned by consulting the ASM manual, online resources, and knowledge from previous projects using the same material. The temperatures and soak times were selected to target a hardness of 55 HRC after tempering.

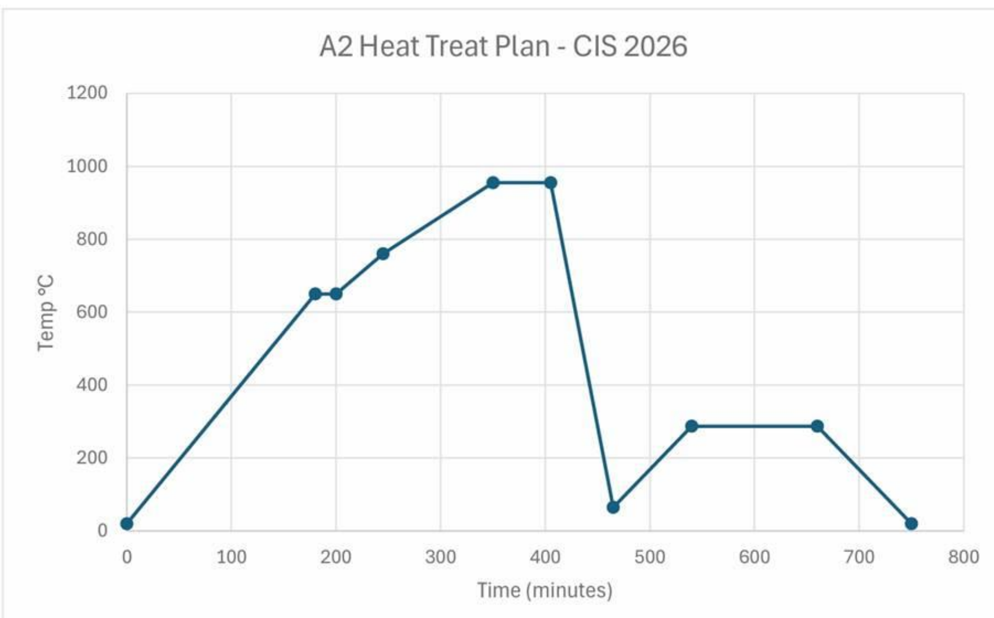

Figure 7: Heat treat process graph

8. Testing

Non-destructive testing consisted of two separate test methods. A Rockwell hardness test was performed pre- and post- heat treat, and an XRF chemical composition test was performed to verify the alloy composition. Hardness tests performed before heat treatment indicated an average hardness of 55 HRC, a post-hardening average of 57 HRC, and a post-tempering average of 52. The XRF chemical composition test showed the percentages of iron (90.12), nickel (0.241), sulfur (0.15), silicon (1.35), carbon (1.23), and chromium (4.83) comprising our tested axe.

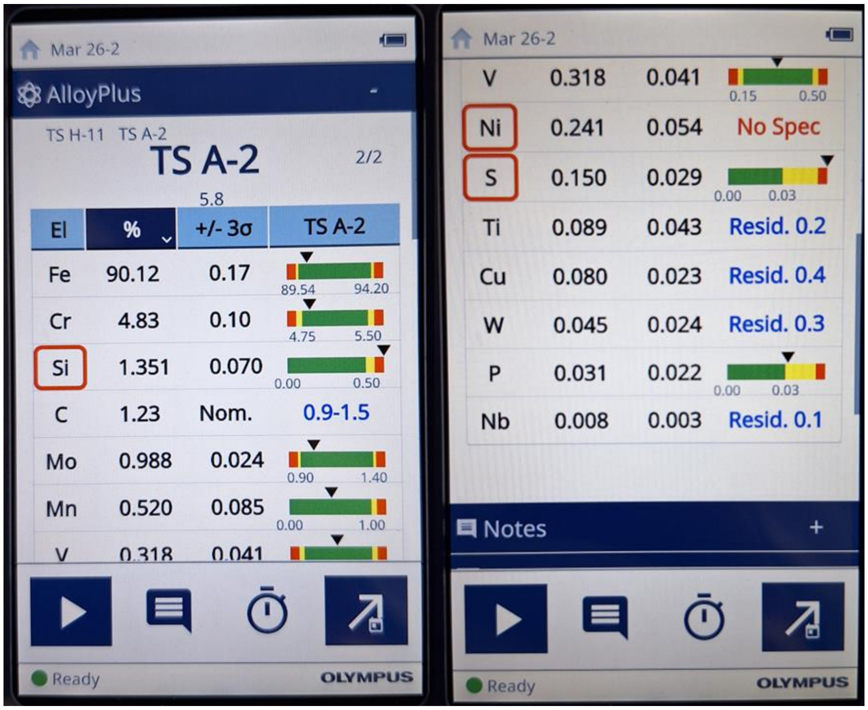

Figure 8: XRF chemical composition results

Performance testing was accomplished by striking the axe against a variety of objects with the first round of testing done standing. These tests included chopping a twenty-ounce bottle full of water in half and impact testing on wood and aluminum with the blade side of the axe. For the spike side of the axe, we tested it on aluminum and formed steel sheet metal. The other method of testing we employed was in-situ testing. We worked with Mary Lewis and her horse Apache to perform tests while on horseback. The testing was done at different paces from a full sprint to a walking speed to emulate the circumstances that a historical horseman would have used the axe in. Testing was done on an aluminum hubcap, a split log, a sheet metal stove cap, and a gallon jug of water.

Performance during testing went better than expected. The axe handled well during standing tests, with no vibration or discomfort to the user. The grip was reliable and easy to control. Using the axe on horseback was effective and worked as intended. The length of the handle did limit reach of a strike, but a shorter length offers better control of the axe. The grip was comfortable to hold and did not slip around while in use.

9. Results and Discussion

The final casting results demonstrated both the strength of our design methodology and the critical role of precise process control. Among the three molds poured, the second mold produced the most successful outcome, yielding two fully formed axes with complete geometry and minimal defects. This confirmed that the combination of glued mold assembly, proper clamping, and an optimized drain time of approximately 50 seconds was effective in achieving a high-quality cast.

The first mold underscored the importance of proper mold sealing. Leakage along the seams restricted metal flow into the handle sections, resulting in incomplete fills. Even so, the axe heads were fully formed, validating the gating layout and directional solidification strategy. The failed drain in this trial further highlighted how sensitive the draining process is to both timing and mold integrity.

The third mold revealed limitations in mold strength and thermal durability. Excessive clamping pressure, combined with elevated pouring temperatures, degraded the binder in the thinner mold sections. This caused structural failure and demonstrated that while reduced wall thickness can improve cooling rates, it must be balanced against structural integrity and thermal exposure.

Overall, the use of 3D-printed sand molds enabled the creation of complex geometries and facilitated the integration of the draining riser system. MAGMAsoft simulations played a key role in predicting solidification behavior and refining drain timing. However, real-world variables—such as assembly inconsistencies—introduced challenges not fully captured in simulation.

Post-cast processing requirements were significantly lower than those of traditional casting methods, confirming the effectiveness of the gating and riser design in minimizing excess material. Heat treatment improved hardness as expected, and functional testing showed that the axe maintained structural integrity and edge retention under impact loading.

Cast In Steel 2026 allowed our team members to learn first-hand what goes into the metal casting process. Overcoming challenges in design and manufacturing, working with modern foundry technology to improve casting quality, and completing a project with industry professionals gave us real experiences to take into future careers. Our axe has been designed to overcome manufacturing challenges and to be a reliable weapon in the hands of a standing warrior or a horseman. We were able to accomplish this thanks to the help of our industry partners: Humtown Products, MAGMAsoft, Trumbull Metal Specialties, YSU Excellence Training Center, Coleman Buchanan, and Mary Lewis & Apache.