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

Rose-Hulman Institute of Technology – Order of the Rose

Figure 1: Full axe after completion during a final weight check.

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Foundry Partner:

Harrison Steel Castings Company

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. In the pursuit of learning about the steel casting industry and process, the student team at Rose-Hulman Institute of Technology, named the Order of the Rose, collaborated with foundry partner Harrison Steel Casting Company to exploit the casting process to fabricate a horseman's axe while meeting specified design and performance criteria.

2. Historical Background

The design of the horseman's axe is informed by two major factors. The first lends it namesake to the weapon, being that the axe is meant to be wielded by a user on horseback. An excessively large weapon would be unwieldy, limiting the ability for mounted cavalry to deliver blows on horseback. The other major factor consists of advancements in armor technology: as plate armor became both more common and durable, maces, hammers, and axes became the weapons of choice owing to their impact and ability to penetrate enemy defenses. For this reason, the horseman's axe often has a spike called a pick opposite the head and perpendicular to the handle, allowing for the full force of the swing to be concentrated at a single point to punch through enemy armor.

Another prominent design choice with pertinent history is the inclusion of langets, or thin metal strips typically seen on polearms, halberds, and spears used to resist shearing forces in the shaft during use. The reinforcement permits the weapon to both deliver and block stronger blows without the handle snapping to leave the wielder defenseless. While this feature did not begin to appear until the latter half of the 14th century, it stands to reason that a form of this advancement could have been present some 50 years earlier during the Battle of Bannockburn, where Robert the Bruce, King of Scots, is often depicted as having defeated Henry de Bohun in single combat using a battle axe.

Our team's axe comprises both langets and a belt hook for authenticity.

3. Design Process

While our team had an initial CAD model we intended to use in constructing the pattern, due to delays in the pattern making and concerns with alloy selection aligning with Harrison Steel's pouring schedules, a revised model and pattern were used for the submitted casting. We ended up casting the axe head in a low-carbon alloy and forge welding high-carbon inserts along the blade edge and spike point. Due to porosity issues and delaminations from the forge welding process, the final axe head geometry was repeatedly redesigned based on the orientation of the remaining material after grinding away major delaminations and porosity. With the weight restriction and the unpredictability of delaminations and porosity, the belt hook, langets, and handle were designed "on the fly" without drawings or CAD models to reference. With the timing of this competition aligning with the busiest time of the year for class projects in our campus machine shops, a majority of the parts and machine work done on the axe head were machined on our three-axis CNC mills which often was the only machine available. Without licensing to CAM software, all programs were written manually and were programmed with cutter compensation allowing for the adjustment of offsets until a desired profile was reached.

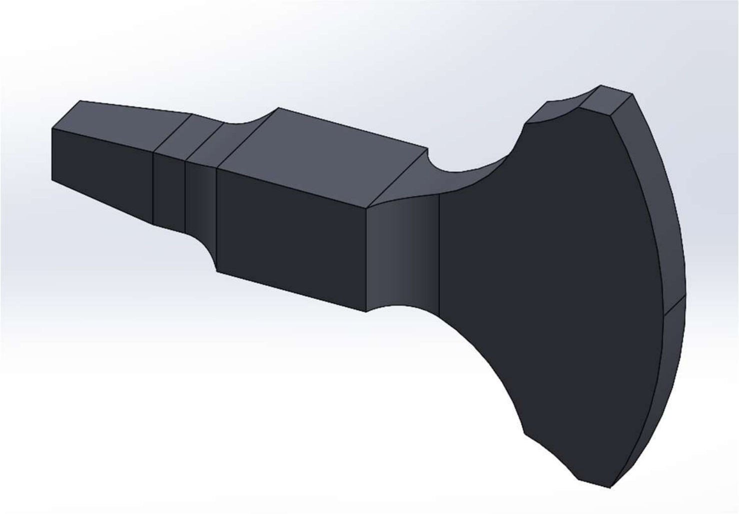

Figure 2: Isometric view of the initial axe head CAD model to be cast.

3.1. Material Selection

Initially our team's plan was to select an alloy from our sponsor's scheduled list and have the heads poured in December. Due to delays in the patternmaking process and scheduling conflicts with our school being on the quarter system, we fell behind and were concerned that a suitable alloy would align with the remaining time we had. Hence, our team had the idea to instead have the heads cast in a low-carbon alloy which would be more likely to be available and forge weld a selected high-carbon insert along the blade and spike. For the high-carbon inserts, 15N20 was elected for the toughness and high contrast during etching due to the 2% nickel content.

4. Simulation

MAGMASOFT is the simulation software used for front-end design to determine pouring parameters for our casting process, including flow speed, solidification rate, and any potential points of porosity or shrinkage for a given rigging design. It is critical to properly design the rigging system to provide for uniform and controlled metal flow. The team primarily leveraged the expertise of foundry partner Harrison Steel Castings Company (Harrison Steel) to make decisions regarding simulating settings, owing to our lack of knowledge of vertically poured castings. Using our finalized CAD model (Figure 2), Harrison Steel constructed two different gating types.

The first gating system is gated in on the blade itself, which is not the largest heat source. This gives rise to significant shrinkage concerns, which compromise the structural integrity of the casting. Another issue associated with this gating system is that each gate allows for the pouring of only one axe head. Both of these problems are addressed by the second gating system (Figure 3), which connects to the eye of the axe, where the center of mass is located.

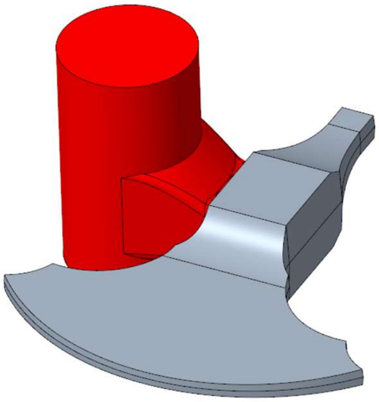

Figure 3: It was determined by the CAD designers at Harrison Steel that a side riser would produce the best result for our casting.

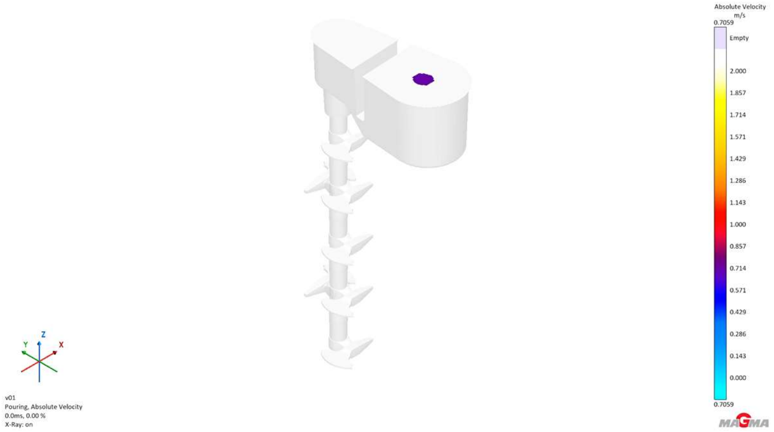

Figure 4: Full view of the tree desing pouring all seven castings.

To check for shrinkage, MagmaSoft uses a solidification software called percent liquid. Using the parameter of 40% liquid as a cut-off, MagmaSoft creates an animation of how it calculates the casting to solidify. While watching the animation, we watch for times when a part of the liquid is pinched off from the rest, which causes major shrinkage. With these considerations in mind, our final rigging design is depicted in Figure 4. The tree arrangement pours seven heads simultaneously, with redundancy giving leeway in the following machining process.

5. Casting

The axe heads were cast at Harrison Steel through sand casting. The 3D model created by our team was 3D printed and placed on a wooden board. Sand was then poured in the flask with the pattern, so that various sand molds could be created. The drag and the cope were obtained by separating the sand mold. These featured the actual mold cavities for the axe heads, a sprue hole, and runner channels that were created by cutting into the sand (completing the gating system). The drag and the cope were coated with a zirconia mold wash, which was torched to dry off volatile agents. This process improves the finish of the cast and helps it release more cleanly. A red compound was used on the coated drag and cope to help separate the sand mold at the end of the process. Before pouring, multiple sand molds were stacked. Different proprietary metal grades were used for pouring, including HS70, HS138, and

HS240. The composition of these grades is close to ASTM A216 WCB, AISI 4140, and 4340, respectively. After pouring, the molds were broken and the axe heads were released.

6. Initial Processing

Our partner Harrison Steel was able to make last-minute changes to the pattern to add thickness to the blade and promptly get them poured before our quarter break so that team leader, Neil, would have them ready to forge weld back home in California. While we were initially anticipating the low-carbon heads to be poured in 1025, due to the urgency and alignment with their scheduling, the heads were poured in one of their proprietary grades, HS70. This grade turned out to be similar to ASTM A216 WCB, which had significant manganese content, which was desirable to help etch dark, but with a wide range of possible chrome content, there were concerns with how well it would forge weld. Hence, the 15N20 inserts were machined to tight tolerances, and all of the seams were MIG welded shut to seal out atmospheric oxygen.

Once the castings were received (Figure 5), the two heads with the least visible porosity and sand inclusions of the six that were cast were selected and rough ground to remove flashing and remaining material from the sprue. Using the cleanest edge on each head's center, the center of the heads were machined square and parallel for slotting operations. These surfaces also provided reference planes for later forge welding, scribing lines for hand grinding, and finish machining.

Figure 5: The two best castings selected from the low-carbon batch.

A 6" diameter slitting saw was used on our campus CNC mills to machine a slot for the blade insert with sufficient depth to provide enough surface area contact for forge welding and allow for significant removal of material close to the MIG welded seams. At the time of machining the slots, we did not have any information on the composition of the heads except that they were low carbon. As a precaution, the heads were normalized to relieve internal stresses from the casting process and prevent the blade from binding.

Residue from the flood coolant on the CNC mill used during slotting was deliberately left on the axe heads, and the high-carbon inserts, until everything was ready to be MIG welded in order to prevent rust from forming and the need for extensive surface preparation.

It was not until the last day of final exam week that the axe heads and their inserts were ready to be MIG welded shut. After morning exams, all mating surfaces were thoroughly deburred and hand-sanded to 600 grit, followed by an acetone wipe-down. When MIG welding the seams, care was taken to have the seams oriented upward toward the exhaust fan to prevent fumes from contaminating the forge-welding interface. The setup for welding can be seen in Figure 6.

Figure 6: One of the axe heads being clamped and prepared for MIG welding

Canisters for the belt hook containing 1084 powder and 15n20 chips that were saved while squaring the insert stock were also sealed, as well as two canisters for the pattern welded text on the front langet of the submitted axe. Unlike typical pattern welding using the canister technique where all sides are sacrificial, the bottom of the belt hook canister was made from a thick piece of low-carbon scrap so that it could still be tapped while having a pattern welded surface.

6.1. Forge Welding

To prevent material loss due to scale formation at welding temperatures, scrap sheet metal was welded around the machined surfaces from the initial machining operations. This helped keep the reference surfaces clean for finish machining and scribing templates during the grinding process.

Without a thermocouple, the forge welding cycles were performed at night in order to be able to gage temperature by eye. The first forging cycles to set the welds were done at close to white hot due to the potential chrome content in the casting. All remaining forging was done at slightly lower temperatures but remained above a bright yellow color to avoid tearing the welds apart.

During initial forge welding cycles, the axe heads were exposed to the direct flame of the burner. To prevent the risk of warping during quenching due to stresses induced by the uneven heating with the center reaching temperature first, a piece of scrap mullite was used during latter forging cycles to block the burner and direct the flame around the sides so that the center reached temperature last. Using the gate valve on the furnace blower and needle valve on the fuel line, a highly reducing flame was set to reduce scale formation within the furnace. The temperature was maintained so that while one axe head was being forged, the other was placed back in the furnace so that it was ready to be worked by the time the one in hand dropped below bright yellow in temperature. Forging was done on alternating sides to reduce stresses from uneven forging which is known to lead to warping during quenching.

After each forging session, a stress relief process was performed by heating the axe heads until they reached non-magnetic, then slowly air cooling in order to relieve internal stresses from forging and help counteract the grain growth that occurred at such high temperatures. During cooling, careful attention was paid to the color changes to ensure that the casting and insert transitioned at the same rate indicating a successful forge weld. Ring testing by holding the axe head at the center of mass and ringing the blade and spike tip was performed to listen to any frequencies that would indicate forge welds that did not take.

6.2. Pre-Heat Treatment Profiling

After forge welding and straightening was completed, the MIG welded seams were ground down and the sacrificial sheet metal was cut off. Unfortunately, underneath the sheet metal a large sand inclusion was uncovered. This was later plunged out with an endmill and MIG welded shut before heat treatment.

When grinding the blade and spike seams, multiple locations on both heads had sections of delaminations where it appears there were sand inclusions (Figure 8) and porosity (Figure 7). As material was lost to scale formation, more of these “worm holes” were likely exposed to the atmosphere and were able to oxidize regions between the insert and casting. The head with the least delaminations, which unfortunately was the one with the large sand inclusion, was chosen to proceed with.

Once all delaminations were ground away, the blade and spike geometry were quickly redesigned and profiled on a contact wheel and a set of files. The bevels were roughed in by hand on a contact wheel then finished by draw filing. Without time to create CAD models or write programs, the geometry, including the grooves on the spike end were designed by plunging or interpolating as much porosity and gouges from rough grinding as possible, then machining or hand filing matching reliefs on the opposing side to maintain symmetry.

6.3. Heat Treatment

To reduce the grain size and prevent the risk of warping during quenching, the recommended procedure from the 15N20 supplier, New Jersey Steel Baron, for normalizing was followed, allowing the axe head to cool to non-magnetic between cycles. After the third normalizing cycle, the axe head was held at the recommended austenitizing temperature for 15 minutes then quenched in canola oil preheated to 130 degrees Fahrenheit. Not only was canola oil an affordable and readily available option, but without knowing the composition of the casting and with the stress from forge welding, grinding, and MIG welding repairs, a slower quenching medium posed less of a risk for delamination and warping than even a faster quenching oil such as Parks 50. After file testing the edge and spike tip to ensure successful hardening, two temper cycles at 400 degrees Fahrenheit were performed to provide a tougher edge while avoiding tempered martensite embrittlement.

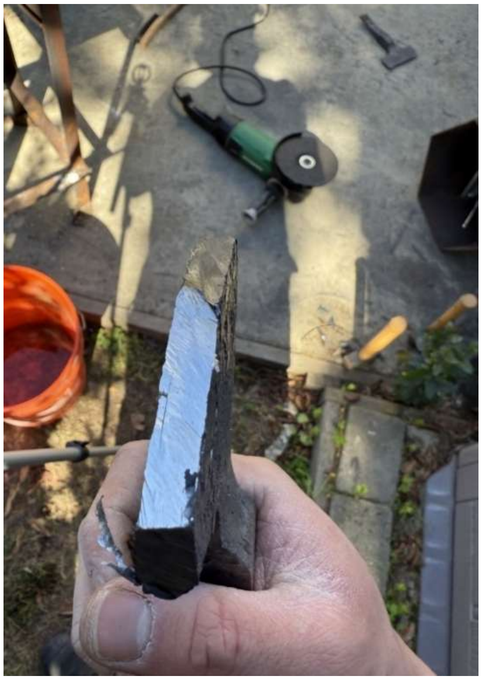

Figure 7: One of the "wormholes" in the casting leading to a partial delamination.

Figure 8: Large Sand inclusion uncovered from material loss due to scaling during forge welding

6.4. Finishing

After heat treatment, the haft hole was machined with tapered walls on the top two-thirds of the pocket. After hand grinding and hand sanding to 600 grit, the axe head and other etched components were given an initial etch in 1:4 diluted ferric chloride then allowed to soak in strong instant coffee for as long as possible to darken. Immediately following removal from the coffee bath, parts were neutralized in a baking soda solution and protected with multiple coats of renaissance wax.

Since we were not able to take part in the casting process due to the aforementioned scheduling conflicts and timing of our final exams, in order to have a “cast” part that we made incorporated into the axe, a pommel was added to the design. In between forge welding sessions, a sealed clay-graphite crucible charged with iron flake, ferrovanadium, ferrochrome, and high purity coal was taken to melting temperatures and an ultra-high-carbon ingot was melted down. After forging slight flats for workholding purposes, the ingot shape matched the selected handle profile with only light finishing passes being required. With the addition of the carbide formers, after etching surface patterns of carbide cluster sheets became visible for decorative purposes.

6.5. Handle Fabrication

Figure 9: The full handle after machining and finishing

The handle was cut and squared from a plank of hickory chosen for its strength and availability. The grain of the handle was oriented to run parallel to the blade and spike to provide maximum strength. A profile matching the haft hole was machined on a 2-axis CNC knee mill in a hickory blank and slotted with a tapered end mill to accommodate a wedge. On the reverse end, a profile was machined to match a pocket machined in the pommel. Once the head was fixed and wedged, a hole was drilled through the handle using the existing hole in the axe head as a drill guide. During assembly, a pin extending through both langets and the fitted axe head was threaded into the belt hook to provide further insurance against the head flying off during use. Once langets were peened in place and the pommel was fixed to the end, the handle was finished with multiple coats of boiled linseed oil followed by a coating of renaissance wax.

7. Results

The final overall length of our axe is 24.5 inches, and the final weight is 1.455 kilograms, both meeting specifications for the competition. An image can be found on the cover page of this report.

8. Testing

In addition to the repeated inspection and verification that was carried out during the entirety of the manufacturing process, a final testing was conducted by striking the drops from the hickory plank used to make the handle. In addition, after spending hundreds of hours filing and hand sanding, our team leader began experiencing hand cramps and dropped the axe head at least a dozen times. The low carbon cladding experienced dents and scratches that were easily blended but the forge welds and high carbon inserts experienced no significant damage.

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