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

Baylor University Huscarls

Team Members:

Andrew Ikeler, Shane Jensen, Michael Flaherty, Tyler Tennant

Advisor Name:

Dr. Brian Jordon

Foundry Partner:

Delta Centrifugal

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2 COMPETITION MOTIVATIONS

2.1 Reason for the 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 to create functional components.

2.2 Reason for Choosing Delta Centrifugal

Dr. Raymond Monroe and David Poweleit connected the team at Baylor University with Delta Centrifugal, as both groups are near in proximity in Central Texas. Our team chose to partner with Delta Centrifugal because of their excellent leadership, cooperative attitude, specialization in custom alloys, and geographic proximity to Baylor University. Each of these aspects is what makes Delta Centrifugal an exceptional place for industrial casting needs, as it produces several million tons of cast parts per year, nearly 80% of which are stainless steels. Delta is renowned for their speed in lead times, and client relationships. Their centrifugal process, precision machine shop, NDE, and high standards ensure satisfaction for the customer with extremely low machining tolerances or part defects. Our group had a desire to learn more about industrial casting processes and the historical aspects of the axe used in daily life and warfare. The Cast in Steel competition offered a great opportunity to learn more about all aspects of the casting process and an opportunity to collaborate between an industrial foundry and students on a fun and common goal. Our team enjoyed being able to work together to balance the design ideas from different members and incorporate the feedback from Delta Centrifugal. It was their first time every pouring a sand casting, and many members had never seen iron sand cast before. Their team provided great feedback and was incredibly informative. Our team taught them about our molds and gating design, and got to tour and learn about how their foundry pours steel.

3 HISTORICAL CONNECTION

3.1 HISTORICAL BACKGROUND OF ROBERT THE BRUCE'S AXE

(Figure 1-Reference Image of Robert the Bruce's Axe)

Robert the Bruce was the king of the Scots from 1306 to 1329. His most notable accomplishment is securing Scotland's independence from England as well as laying the foundation of the modern Scottish monarchy. As referenced in figure one Robert the Bruce is known for wielding an Axe as before the battle of Bannockburn, in 1314, with a single blow to the head he killed the English knight Sir Henry de Bohun. This cemented his legacy, boosted the Scottish Army's moral and is why he is associated with using an Axe in Battle.

Since the battle took place in 1314 the design of the Horseman's Axe was a direct result of medieval warfare. Specifically, as a reaction to improvements in Armor, specifically the improvement to plate armor, which led to more traditional weapons like swords being much more ineffective. Thus, weapons like Axes which could deliver high impact and penetrating blows that could pierce armor due to their ability to concentrate force. Although, axes where uncommon to be a main weapon they were often carried as a secondary weapon, as a result of their versatility and effectiveness against armored foes. One handed axes were preferred due to the prevalence of the use of horse in combat and the need for a hand to maintain control of the horse.

Based on the axes from the 14^{th} century that have survived to this day illustrated the functionality of the design, from larger shafts to prevent structural failure, wrist straps to keep the weapon during combat or even belt hooks for convivence when not in use. These characteristics emphasize a clear emphasis on durability, retention and ease of use.

3.2 DESIGN AUTHENTICITY

Baylor University's team design is an original design, inspired by the Horseman's Axe used by Robert the Bruce. The main blade of the Axe was made thin to match the cutting ability needed for axes during this time period. As a sharper edge angle allows the blade to cut deeper into the target. A rear spike was incorporated to replicate historical armor piercing features used by mounted combatants. The handle was made of thick wood as at the time metal was a much scarcer and thus it would be wasteful to make the handle out of metal when a think piece of wood accomplishes the same result.

4 METALLURGICAL DECISIONS

440C stainless steel was chosen for its high hardenability and ease of pour. Delta pours approximately 80% of its melts as stainless steel, and recommended 440C because it pours well. It is the hardest of the stainless steel alloys and can be readily heat treated to make a sharp blade. The team's familiarity with this alloy and its known properties of high strength, ductility, and its high 1% carbon content made 440C a strong choice. These properties make for a axe with high toughness that can withstand impacts during high performance applications, such as hand to hand combat.

5 TIMELINE AND PROCESS

April 2025: Initial meeting between Delta Centrifugal's Kris Jones and Baylor University. Team toured their facilities and learned about their centrifugal casting process.
June 2025: Delta Centrifugal tours labs at Baylor Univ and brings large stainless steel pipes. Address issues in the casting industry how many parts are scrapped because internal shrinkage details may affect the part's life. Address unknowns about solidification modeling for centrifugal castings.
July 2026: Baylor Univ conducts X-Ray CT on Delta Centrifugal's parts and identifies the indications with Kris Jones. Baylor Univ develops a 1-D heat transfer model in Excel to Delta.
December 02nd : Preliminary Plan Due
February 3rd : Axe and mold design completed, parts 3D printed.
February 11th : Meeting with Delta Centrifugal: Finalized material choice and designing the gating to prepare for the upcoming trip.
March 19th : Pour 440C into sand molds during visit to Delta Centrifugal. The team documented the process in-depth and participated in every step of the casting process.
March 20th- : Team continued writing the report, editing the video, conducting material property tests, and machining the axe.
March 27th : Axe, Report, and Video due.
April 13th : Competition in Grand Rapids, Michigan.

5.1 DESIGN

There are many calculations to determine how quickly the metal will cool which determines how large the gating system and risers should be. The team has previously used FLOW-3D simulations to visualize how the metal flows from the pour cup to the mold to the risers to the gating. The group did not use solidification modeling and estimated gating sizes large enough for the metal to flow. Five different gating designs were chosen to ensure at least two molds would properly fill as a precaution. The goal is to minimize shrinkage, porosity, and unwanted inclusions in the axes.

Figure 2. Five different gating designs were redundancies to ensure at least 2 would properly fill.

5.2 Sand

Sand casting was used to make the axe as it is a versatile and effective method to cast many complex designs. Sand is used to help dissipate heat and maintain shape.

5.3 Mold Dimensions

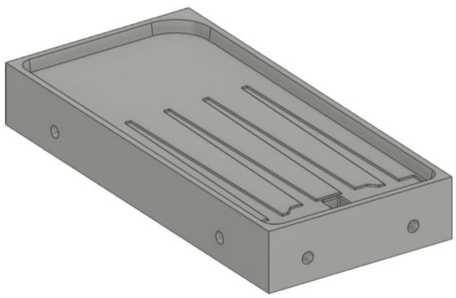
The clean weight of each axe was 2.5 lbs. but required about 10 lbs. of pour weight for the pour cup, gates, and risers to ensure less quality details found in the casting. This gives a yield of 25% usable material. Some unused material was cast into test bars for both the Baylor University team and a 3rd party to test and compare material properties. The full gating system included the following:

Table 1) Mold Box Components

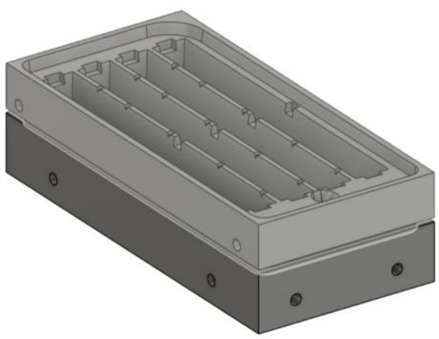
There was 1 core and 2 risers for each axe assembled according to the following diagram:

Once packed, the sand activates by moisture evaporating from the sand to harden it. To prepare for casting, a pour box was placed on top for the crucible to pour into, and the mold was tied down for transportation. Representative components of the mold box are shown below:

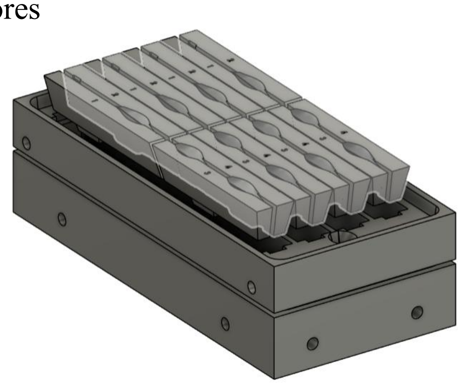
Drag



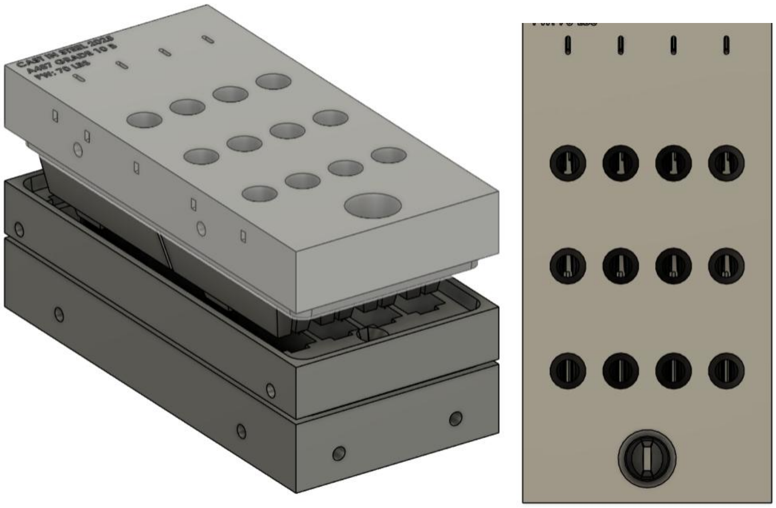
Cheek



Cores



Cope



Full gating system where the metal will flow

Figure 5) CAD models of the drag, cheek, cores, cope, and gating system.

5.4 Melting and Alloying

Delta Centrifugal uses an induction furnace to melt the metal. The metallurgists use a variety of alloying materials for each cast to meet the customer's specific material requirements. Delta can cast almost any alloy with any mixture of materials. Our team chose 440C because the high content of Cr, Mo, C produce a good mixture of corrosion resistance, strength, blade hardenability, and ductility. First, the furnace was charged with low carbon iron and 316L/304L SS. Once the pot was half full of liquid, the low carbon FeCr and FeMo were added. Then the metallurgist added FeSi and the remaining low carbon iron and recycled SS. The metal alloy has a liquidus temperature of 2550°F resulting in a target pouring temperature of 2880°F. Samples were taken from the molten mixture, polished, and examined in an optical emission spectrometer (OES). The final alloy measured from OES resulted in the following composition:

Figure 6) Optical emission spectrometer used to determine composition of a sample of the molten steel alloy prior to casting.

	C	Si	Mn	P	S	Cr	Mo	Al	Cu	Ti	Fe
Axe	0.95	.251	.639	.018	.0081	.792	.641	<.001	.0037	<.001	Balance

Table 2) Custom composition of 440C stainless steel, measured from optical emission spectrometer.

Once the alloy met the team's requirements, the molten mixture was moved to a crucible via overhead crane and poured into the mold. The mold was left overnight to solidify and was shaken out the next day.

Figure 7) Axe mold box after the pour and axes after removing gating system.

5.5 Heat Treatment

The axes underwent a heat treatment according to ASTM standards for temperature. The axe was held at 1020°C for 2 hours and cooled in the furnace at a rate of -10°/hour to anneal the material. After the metal was softened to a hardness of approximately 25 HRC, the machining was completed on the axes. To harden the axes, the metal was held at 1020°C for 1 hour and immediately air quenched under compressed air. This process transforms the phase into austenite by holding it above its solvus temperature. The rapid air quench locks the microstructure into an

HCP martensitic structure. To temper the brittle martensitic structure, the axe was placed back in the furnace at 375°C for 1 hour, cooled then second tempered to convert all retained austenite to martensite and reduce internal stresses. The annealing and hardening process has been used for thousands of years to strengthen steel. The blacksmiths that built horsemen's axes likely followed a similar process to anneal, quench, and temper their weapons.

Figure 8) Insulated furnace used for annealing, quenching, and tempering the blade.

5.6 Machining, Grinding, and Sharpening

To reduce machining time, the axe mold was designed to the near net shape. The eye profile where the handle joins the steel was created with cores during the casting. The team machined then grinded the edge to sharpen it. No welding or forging was applied to this blade. The team opted to grind the side down to get an edge using various belt grinders, angle grinders, bench grinders, and sharpening stones.

The team used a wire fed electronic discharge machine (Wire EDM) to machine the axe eye profile into the axe.

The team would like to thank Baylor University and its machine shop for lending its equipment to our team during the post processing stage. For more in-depth information on the axe's post processing, see the 2026 Cast in Steel video submission by the Baylor Huscarls.

6 Finite Element Analysis

A static stress study was conducted in SolidWorks to approximate the stresses being withstood during a stabbing and slashing motion. The main goal of FEA was to understand the deflection and location of highest stress when a large load is applied. This is a high stress, but the axe thickness and rigidity ensures our confidence that this axe is well designed to deal with extreme impact.

a)

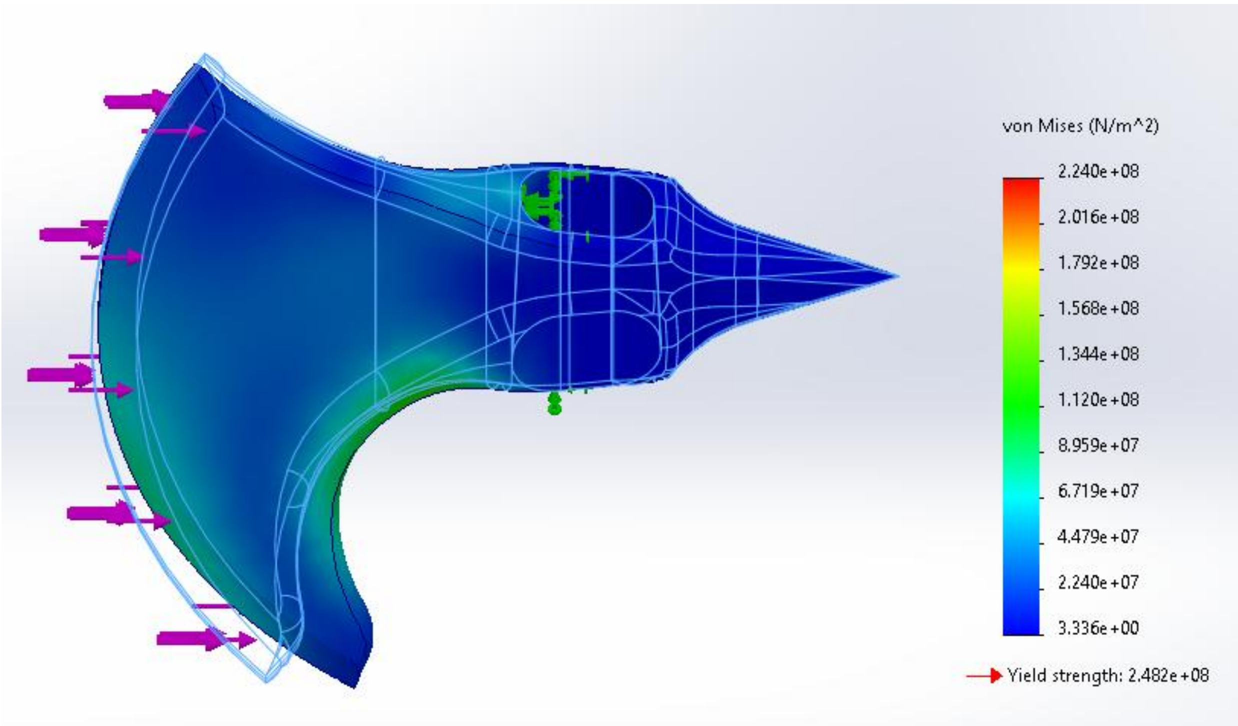


Figure 9: Finite element analysis of stress and displacement after maximum force applied by an average human swing.

7 Final Results

The Baylor University Huscarls had a great experience during this process and are pleased with the results. The team visited the foundry to help with the casting process at Delta Centrifugal including designing the model, building the sand molds, preparing the mold box, alloying the steel, and heat treating the blade. Next, the team undertook machining and grinding the blade in-house at Baylor University. It was an unforgettable experience full of learning to be a part of every step of the process. This process has taught our team countless lessons about this work that will last a lifetime. This project has sparked a new appreciation for casting and the capabilities a foundry and university can accomplish when working together.

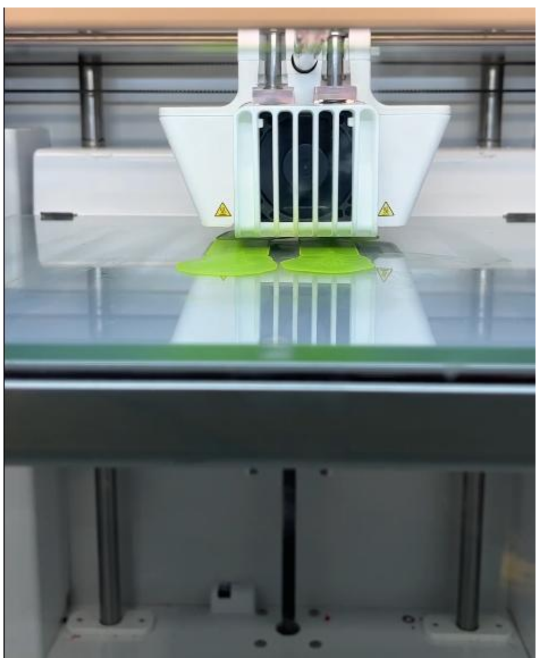
Figure 10) Final results of the axe created by the Baylor University Huscarls.

APPENDIX A: EQUIPMENT USED DURING POST-PROCESSING

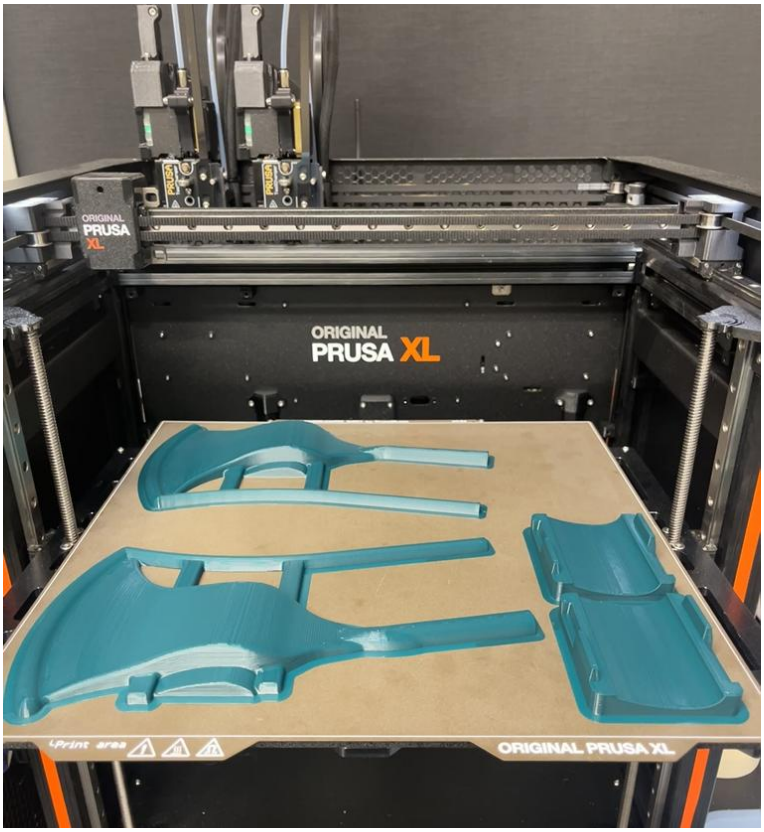
Anvil can be used to forge the axe

Furnace used to heat the steel for forging and melt bronze for casting

HAAS CNC machine used for subtractive machining of the axe.



Ultimaker S3 Printer used to create a plastic mold of the axe profile for sand casting



Wire EDM used to cut the sawtooth pattern into the blade using 2D CAM.