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

Pittsburg State University – Gorilla Warfare

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Introduction

Cast In Steel Overview

The Cast In Steel competition, hosted by the Steel Founders' Society of America (SFSA), challenges engineering students to design, manufacture, and test a fully functional steel tool, made by exploiting the casting process. The competition emphasizes practical foundry engineering, real-world design constraints, and performance-based evaluation. For the 2026 competition, teams were challenged to manufacture a replica of a Horseman's Axe.

Historical Background

The Horseman's Axe, associated with Robert the Bruce and Scottish cavalry, was designed for mounted combat, emphasizing balance, durability, and cutting power. Key features for authentic replication include its relatively small size, a slightly curved single-edged blade, and a rear spike opposite the cutting edge for striking between the armor of opponents. Preserving these features in our design ensures both historical accuracy and authenticity. Shown below is an example of the Horseman's Axe.

Design Stage

The design of the Horseman's Axe focused on creating a structurally sound, manufacturable, product, while maintaining historical accuracy and functional performance.

Design Inputs

The competition specifies a maximum assembly weight of 3.3 lbs. and a maximum overall length of 31.5 in., while also implying that the final product must withstand rigorous performance testing. In addition to these constraints, several design inputs were considered to ensure the axe would perform reliably during competition testing. Numeric inputs included requirements for adequate material hardness (for all steel components), blade sharpness, and structural integrity suitable for repeated loading. To verify casting quality, porosity in the axe was required to be less than 10%. Additional binary inputs specified that the axe must survive full-force impact testing without cracking or deformation. See Appendix A for detailed numeric and binary inputs. These expectations guided the design, material selection, casting strategy, and test plans used in the development of the final axe.

Design Considerations and Intent

Design considerations for this product focused on manufacturability, strength, and aesthetics. Visual features such as the Pitt State gorilla face on the axe head and the SFSA logo on the pommel were incorporated to enhance appearance while maintaining functional geometry. Design considerations for the Horseman's Axe focused on achieving a balance between manufacturability, structural performance, and visual appeal while maintaining historical authenticity. Aesthetic elements, including the Pitt State gorilla face on the axe head and the SFSA logo on the pommel, were intentionally incorporated to enhance appearance without compromising functional geometry. Casting-oriented design practices were applied to maximize value added during manufacturing. Smooth fillets were used in place of sharp corners to reduce hot spots during solidification and to minimize stress concentrations during impact testing. Solidification shrinkage factors were incorporated into all metal components to ensure dimensional accuracy following casting. Weight reduction and stiffness preservation were key considerations in shaft design, leading to the inclusion of an internal pocket. The shaft also features a 3/8"-16 exterior thread to allow attachment of the pommel, with 0.6 in. of thread engagement selected to provide reliable fastening between aluminum and steel components. Handle ergonomics and overall length were optimized to enable both one-handed and two-handed operation during use. The complete bill of materials is provided in Appendix B.

Casting Technology and Processes

The axe head, the primary functional component of the assembly, was produced using investment casting to accommodate complex geometry, gradual section transitions, and intricate surface features such as the Pitt State gorilla face mentioned previously. This process also provided improved dimensional accuracy and reduced likelihood of internal defects in critical regions. Unlike the axe head, which utilized a wax pattern, the gorilla head was manufactured using the lost PLA casting process. The green sand casting process was selected for the pommel, allowing reduced tooling costs and improved economic feasibility for higher production volumes.

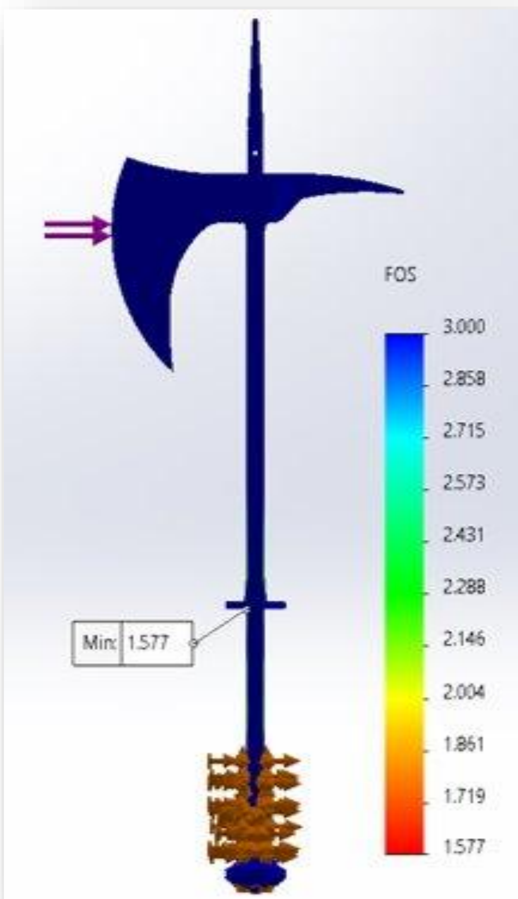
Material Selection and Metallurgical Decisions

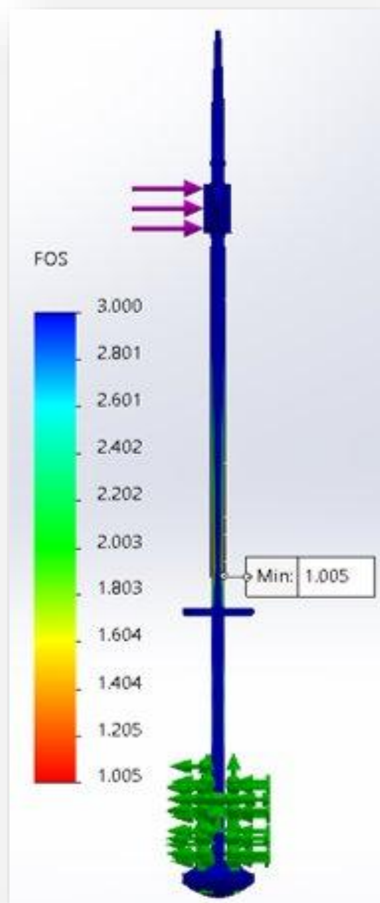
Material selection was guided by the need to balance strength, durability, and weight across each component. Load-bearing components including the axe head, shaft, and guard were produced from 5160 spring steel to provide high toughness and impact resistance. In contrast, the pommel and gorilla head were cast from A356 aluminum to reduce weight in areas where high strength was not necessary.

A hickory wood handle was selected due to its traditional use in striking tools and its proven ability to absorb shock. Heat treatment was applied to all steel components to achieve hardness targets outlined in the design inputs. Laser hardening was performed along the blade edge to improve wear resistance while maintaining sufficient toughness for repeated impact.

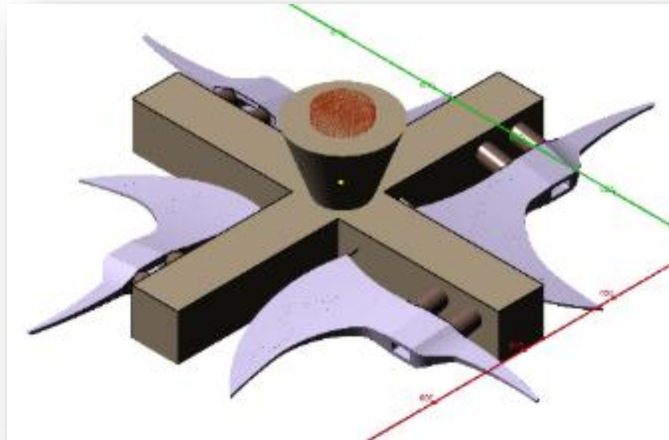
Finite Element Analysis (FEA)

Finite Element Analysis conducted in SolidWorks was used to verify structural performance prior to manufacturing. A 160 lb. force was applied to the front of the axe head to simulate loading during a conventional swing, with supports located along the handle to resist the load. In an additional simulation, a 120 lb. force was applied laterally to represent unconventional torsional loading conditions that could occur during use. Results indicated that the shaft would withstand both bending and torsional loads, achieving a factor of safety (FOS) of 1.577 in the strong orientation and 1.005 in the weak orientation. The results are shown visually in the corresponding figures (strong orientation on the left, weak orientation on the right)





Casting Simulation



Casting simulations were performed using Magmasoft to validate the gating strategy for the axe head. Both filling and solidification analyses were conducted across several gating system iterations. Because steel pouring operations were completed at Monett Metals, their team was consulted to determine which existing wax tree configuration would be most suitable. One promising gating system demonstrated favorable performance in simulation and is shown in the figure on the right. Further improvements were achieved with assistance from Magmasoft consultant Joe Mader, who recommended modifications including a revised orientation and minor gating adjustments to improve wax burn-out. This updated design oriented the axe heads vertically during filling. Simulation results confirmed that fluid velocities within the gating system would not cause mold erosion or air entrapment, while solidification analysis showed improved directional solidification and reduced hot spots. Ultimately, both gating iterations were produced.

Fixtures and Tooling

Custom fixtures and tooling were developed to support manufacturing and secondary processing operations. For investment casting, the axe head required a wax injection mold, followed by a drill jig to ensure accurate and repeatable hole placement, and a dedicated sharpening fixture to maintain consistent edge geometry during belt finishing. The wax injection mold is shown in the referenced figure. The pommel was produced using a sand casting match plate and later processed using a drill and tap fixture for reliable post-processing. A separate match plate was created for the top insert to improve molding efficiency and dimensional consistency. Many fixtures were produced using additive manufacturing due to its short lead time, low material cost, and adequate surface finish for tooling applications.

Manufacturing Stage

Casting and Machining Operations

Manufacturing began with investment casting of the axe head, where wax patterns were injected, assembled into trees, repeatedly dipped in ceramic slurry, and ultimately poured with molten steel. Steel material was donated and poured at the Monett Metals foundry. The pommel was produced by ramming green sand around a 3D-printed match plate pattern, while all aluminum components were poured in-house. Shaft profiles and the guard were laser cut from steel plate by Hix Corporation. Following cutting, shafts were machined on an in-house CNC mill to create weight-reducing pockets and tapered spike features. Gorilla head patterns were 3D printed, assembled into trees, and sent to Monett Metals for casting. The wooden handle geometry was produced using a wood router. A key lesson learned during this stage was that machining shafts from solid stock could provide improved efficiency compared to relying exclusively on laser-cut blanks. Another lesson learned was the importance of planning for long lead times; therefore, a top insert was developed as a contingency in case the gorilla heads were not returned from the foundry in time. Detailed routing sheets for manufacturing operations are included in Appendix A.

Heat Treatment and Post-Processing

Heat treatment of all 5160 steel components was performed by Trojan Heat Treat, Inc. to achieve the required hardness and toughness defined in the design inputs. The blade edge was subsequently laser hardened by Preco, LLC. Post-processing operations included drilling and edge sharpening of the axe head, while aesthetic features such as the gorilla design were intentionally left in the as-cast condition to preserve fine detail. The pommel was drilled and tapped to prepare for threaded assembly. All metal components were ground and polished to improve both visual appearance and assembly fit. The wooden handle was sanded and finished to enhance ergonomics and provide a secure grip during use.

Assembly

Final assembly involved fastening the axe head to the shaft using 3/16 in. diameter brass rivets, which were also used to secure the gorilla head to the shaft. Epoxy was applied during attachment of the wooden handle to the shaft, and the shaft surface was scored to improve adhesion. Thread locker was applied to the shaft and pommel threads to ensure reliable retention during impact loading.

Quality Control and Assurance

Quality steps were performed throughout manufacturing to verify that all components met dimensional and assembly requirements prior to formal testing. Critical features such as overall length, weight, and all mating surfaces were measured using standard inspection tools to ensure conformance with design specifications. Visual inspections were also conducted after casting and machining operations to identify surface defects, incomplete features, or distortion. These quality checks confirmed proper fit of components before proceeding to non-destructive and destructive testing.

Testing Stage

Non-Destructive Testing (NDT)

Testing efforts focused on confirming material integrity and functional performance prior to competition evaluation. Liquid dye penetrant (LDP) testing was conducted in-house to detect surface porosity or cracking on the axe head. X-ray testing, performed by ACME Foundry, and ultrasonic testing, conducted by Mid America Pipe, were used to identify internal defects. Results from these inspections confirmed that the design criterion of less than 10% porosity was achieved. Blade sharpness was also evaluated using BESS testing, which indicated that the cutting edge exceeded 400 BESS.

Destructive Testing (DT)

Destructive testing was performed to validate impact resistance and durability under simulated competition conditions. Rockwell C hardness testing of the axe head, shaft, and guard was conducted by both Trojan (after heat treatment) and Preco (after laser hardening). Preco also performed cross-sectional evaluation to confirm complete hardening of the blade edge. A dedicated swing test fixture was developed to replicate full-force impact loading in a controlled and repeatable manner. Although effective, a key lesson learned was that standardized impact methods such as Izod or Charpy testing could provide comparable material performance insights with reduced setup complexity. Additional instrumentation included the use of a strain gauge to monitor shaft response during loading, which proved more precise than earlier attempts to measure physical deflection manually. These improvements enhanced the team's ability to quantify structural behavior during testing.

Final Result

The completed product is a functional replica Horseman's Axe that meets both structural and aesthetic objectives. The use of 5160 steel provides the necessary strength and durability, while the hickory handle contributes ergonomic comfort and visual contrast. Figures of individual components prior to final assembly are provided in Appendix C.

Design Outputs

Design requirements were verified through comparison of measured and tested results to the original design inputs. The final axe assembly achieved an overall length of 26.5 in., satisfying the competition requirement of a maximum 31.5 in. The total assembly weight was measured at 3.2 lbs., meeting the specified maximum of 3.3 lbs. After x-ray and ultrasonic testing, the porosity of the competition axe was found to be negligible. This meets our requirement of less than 10% porosity, confirming acceptable casting quality. Rockwell C hardness targets were also achieved for all steel components, validating the effectiveness of material selection and heat treatment processes. All testing and quality documentation can be found in Appendix C.

Conclusion

The development of the Horseman's Axe for the 2026 Cast In Steel competition successful demonstrated a balance of functionality, durability, historical authenticity, and manufacturability. The project strengthened the team's understanding of project management and execution. Manufacturing experience was gained within a real-world foundry environment. Overall, this project demonstrated the importance of combining analytical tools, hands-on manufacturing experience, and validation testing to achieve a high-performance cast steel product.

References

"2026 Competition." *Cast in Steel*, www.castinsteel.net/2026-competition.