SFSA Cast In Steel 2026 – Horseman's axe.

Technical Report

Instituto Tecnológico de Morelia – "Pony's Foundries"

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Abstract.

This technical report presents the design, casting, and manufacturing process of a horseman's axe developed for the SFSA Cast in Steel Competition. The project focuses on the application of steel casting technology combined with historical research and modern engineering tools. A cast martensitic stainless steel conforming to ASTM A743 Grade CA40 was selected due to its high strength, hardness, and wear resistance, as well as its ability to develop a martensitic microstructure through heat treatment, ensuring edge retention and structural integrity. The axe was designed in SolidWorks, drawing inspiration from documented horseman's axes, and subsequently modified to enhance castability, facilitate mold removal, and control potential defects. Both the polymer pattern and the feeding system were produced through 3D printing and utilized to manufacture sand molds capable of producing two axe heads per mold. Casting, post-casting operations, machining, and surface finishing were performed at Fundidora Morelia. Non-destructive inspections (NDT) and dimensional verification were conducted to ensure the structural integrity and quality of the final component.

Introduction.

The Steel Founders' Society of America (SFSA) Cast in Steel Competition promotes experiential learning in steel component design and manufacturing through the application of modern casting technologies. Within this context, undergraduate teams integrate engineering design, materials selection, and manufacturing processes in collaboration with the steel casting industry. This project focuses on the design and manufacture of a late medieval horseman's axe, selected for its structural complexity and stringent mechanical requirements. The component was designed using computer-aided design CAD tools, incorporating design-for-casting principles, and manufactured by sand casting using the selected CA40 martensitic stainless steel. Subsequent machining, surface finishing, and non-destructive inspections were performed to ensure structural integrity and compliance with SFSA competition requirements.

Historical background.

The horseman's axe emerged during the late medieval period as a specialized weapon optimized for mounted combat. As armor technology advanced throughout the 14th and 15th centuries, these axes integrated a reinforced cutting blade with compact proportions and balanced mass distribution. This configuration allowed mounted warriors to deliver powerful downward blows while maintaining control and mobility. Unlike longer polearms intended for infantry combat, the horseman's axe emphasized impact efficiency and maneuverability when used from horseback [1].

Figure 1. Robert the Bruce depicted alongside other notable figures from the Wars of Scottish Independence.

A well-documented historical example of this weapon's effectiveness occurred during the Battle of Bannockburn (1314), when Scottish King, Robert the Bruce, mounted and armed with an axe, confronted the English knight Sir Henry de Bohun. Bruce avoided evaded Bohun's lance charge and delivered a decisive overhead strike that split his opponent's helmet, resulting in immediate death [2]. Contemporary accounts describe this event as a clear demonstration of the functional battlefield use of a mounted horseman's axe rather than a ceremonial or infantry weapon [3].

Figure 2. Depiction of Robert the Bruce killing Sir Henry de Bohun during the Battle of Bannockburn.

It is worth noting that, like any noble of the royal court, Robert adorned his clothing and weaponry with symbols alluding to his royal lineage, such as the lion, commonly associated with medieval kingship, symbolized courage, strength, and royal authority, while the fleur-de-lis represented legitimacy, nobility, and divine sanction within medieval European heraldry [4]. Together, these elements reflect the dual nature of the horseman's axe as both a weapon of war and an emblem of noble identity, principles that informed the historical inspiration and aesthetic design of the axe developed in this project.

Design process and CAD development.

The design process of the axe was guided by the objective of achieving historical accuracy while ensuring manufacturability through sand casting. Initial design criteria were defined based on historical references to late medieval horseman´s axes, focusing on functional elements such as a wide cutting blade, a reinforced central socket, a rear spike, and a top spike. These features were intended to withstand high impact loads and multidirectional stresses associated with mounted combat while maintaining appropriate balance and mass distribution (Figure 3).

Figure 3. CAD design of the Horseman's Axe.

The 3D model of the axe was developed using SolidWorks. During the CAD phase, the geometry was iteratively refined to incorporate design for casting principles. Draft angles (ranging from 2° in general geometries to 10° in engraved features) were added to facilitate mold removal, fillets were applied to reduce stress concentrations and improve metal flow (Figure 4), and abrupt geometric transitions were mitigated to minimize the likelihood of casting defects. The blade relief features were implemented as detachable pattern inserts to improve mold release and ensure accurate reproduction of fine surface details.

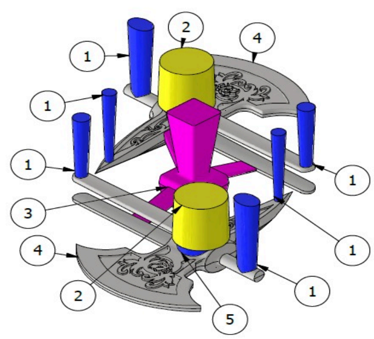

Figure 4. CAD model of the gating and feeding system designed to produce two Horseman's axe heads per mold, optimized for efficient metal flow and defect reduction.

Special attention was devoted to the design of the gating and feeding system, which was integrated into the CAD model to enable the production of two axe heads per mold (Figure 4). This configuration was selected to improve process efficiency and reduce material waste while promoting uniform filling and controlled solidification. The design decisions were consistent with standard sand casting practices, considering factors such as molten metal fluid dynamics, shrinkage compensation, and defect mitigation [5].

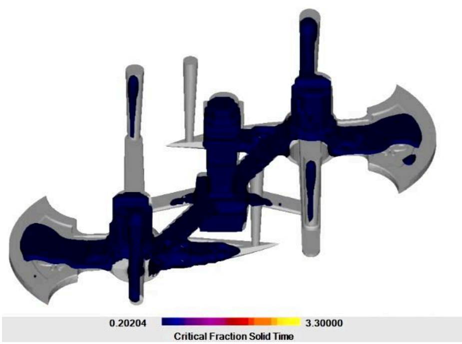

Figure 5. Solidification simulation of the complete casting system, illustrating temperature distribution and controlled solidification behavior throughout the axes and feeding elements.

Polymer patterns for both the axe head and the feeding system were produced via 3D printing, enabling rapid prototyping and accurate reproduction of complex geometries. The integration of CAD-based design and additive manufacturing facilitated close collaboration between the design team and the foundry, ensuring that the final geometry satisfied both functional requirements and manufacturing constraints prior to mold fabrication.

Material Selection and Metallurgical Justification

Figure 6. Representative industrial applications of ASTM A743 Grade CA40 cast martensitic stainless steel [7]

In collaboration with the sponsoring company, an in-depth evaluation of potential materials was conducted for the axe. After considering several alternatives, the selected CA40-grade martensitic stainless steel was selected as the most suitable option. This decision was based on its well-documented mechanical and physical properties due to its various uses in demanding applications such as turbine components (hydraulic, steam, gas, and wind) and heavy machinery parts, mining and industrial equipment and many other uses that are subjected to high mechanical stress and wear [6], as well as the company's prior experience successfully manufacturing axes for a previous competition using the same alloy.

Chemical Composition		
Carbon	C %	0.200 - 0.400
Silicon	Si %	1.500 max.
Manganese	Mn %	1.000 max.
Phosphorus	P %	0.040 max.
Sulphur	S %	0.040 max.
Chromium	Cr %	11.500 - 14.000
Nickel	Ni %	1.000 max.
Molybdenum	Mo %	0.500 max.
Iron	Fe %	Balance

Table 1. Standard composition of ASTM A743 Grade CA40 [4].

As part of the design optimization process, a decision was also made to reduce the number of welded pins used in the assembly. This modification aimed to decrease potential stress concentrations along the handle, thereby improving the overall structural integrity of the axe and reducing the risk of localized failure during use.

Molding and casting process.

The manufacturing of the horseman's axe head was performed using the sand casting process in direct collaboration with Fundidora Morelia. This technique was selected for its efficiency and suitability for CA40 martensitic stainless steel, in addition to leveraging the company's previous experience in producing similar components.

Figure 7. Half of a completed double mold after removal of the polymer patterns.

For this project, six molds were fabricated using the 3D-printed axe pattern and feeding system. The polymer patterns incorporated both the final axe geometry and the integrated gating and feeding system, which was designed to produce two axe heads per mold. The selection of molding sand was a critical consideration due to the high pouring temperature of the steel. Ceramic sands were employed for their high refractoriness, low thermal expansion, and high permeability.

Once the molds were assembled, five molds were arranged in a semicircular configuration around the induction furnace to facilitate a controlled and continuous pouring operation. This arrangement minimized handling distances and ensured consistent pouring conditions. Prior to pouring, each mold was visually inspected to verify alignment, closure integrity, and proper placement of the gating and feeding components.

Figure 8. Four molds prepared and positioned for pouring.

The steel was melted in an induction furnace and brought to the appropriate pouring temperature for CA40-grade martensitic stainless steel. After achieving thermal and chemical stability, the molten metal was transferred using a ladle and poured sequentially into each mold. The pouring process was performed by a single experienced melter to maintain consistency in flow rate and filling time, thereby reducing variability among castings. Care was taken to maintain a steady molten metal flow to prevent turbulence, air entrapment, and premature solidification.

After pouring, the molds were left undisturbed to allow controlled solidification and cooling. The use of exothermic sleeves and the designed feeding system promoted directional solidification, minimizing casting defects. Following solidification, the molds were allowed to cool for an extended period to reduce thermal stresses and distortion prior to shakeout.

Figure 9. Melter actively pouring molten ASTM A743 Grade CA40 steel into one of the molds.

Post-casting operations and assembly.

In addition to the cast axe head, the remaining components of the horseman's axe were manufactured through precision machining processes. The wooden handle was produced by CNC machining from maple wood, selected for its mechanical strength, dimensional stability, and suitability for impact applications. The CAD model of the handle was adjusted to account for material removal during machining, and the final geometry was achieved through controlled CNC milling.

Subsequently, the handle was further machined to carve the fleur-de-lis motifs defined in the three-dimensional design, ensuring consistency between the historical symbolism and the final component.

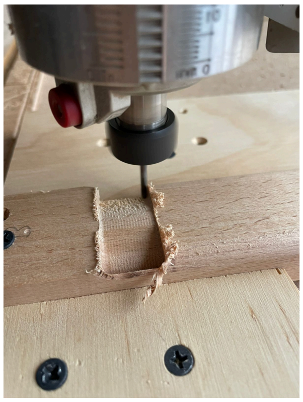

Figure 10. CNC machining process beginning the shaping of the wooden handle.

The hook, fastening pin, hand guard, and pins were manufactured from metallic stock using CNC machining according to their respective engineering drawings. These components were produced to precise tolerances to ensure proper assembly, structural integrity, and alignment with the axe head and handle. The hand guard was then subjected to a sand blast process and painted to engrave the heraldic symbols associated with Robert the Bruce, transferring the designed iconography onto the metal surface with controlled depth and definition.

Figure 11. Machined handles prepared for abrasive carving of decorative details.

After casting and initial machining, the axe heads underwent three sequential heat treatments to achieve the desired mechanical properties. The first stage consisted of annealing to homogenize the microstructure and reduce internal stresses generated during solidification and cooling. This was followed by quenching to increase hardness and strength through microstructural transformation. Finally, a stress-relief treatment was applied to reduce residual stresses induced by quenching and machining, thereby improving toughness and minimizing the risk of distortion or cracking during service.

Figure 12. Axe heads undergoing annealing heat treatment.

Inspection and non-destructive testing.

Hardness tests were conducted using an Equotip Proceq device, which provides measurements in Brinell (HB) as well as other scales.

Figure 13. The Equotip actually uses the Leeb rebound method (HL) to measure hardness, which it then converts electronically to Brinell (HB).

Hardness tests were conducted after oil-quenching the axe head.

Test	Hardness Brinell
1	479
2	488
3	405
4	481
5	512

Table 2. Hardness results of ASTM A743 Grade CA40 after oil-quenching.

As part of the non-destructive testing, the axe was used to cut different materials, including two distinct aluminum samples to evaluate both components of the axe, the cutting edge and the spike.

Figure 14. Results of the tests on an aluminium plate using the axe's spike.

The tests demonstrated excellent penetration capability of the spike, producing several perforations several centimeters deep in the steel plate used, without showing any deformation.

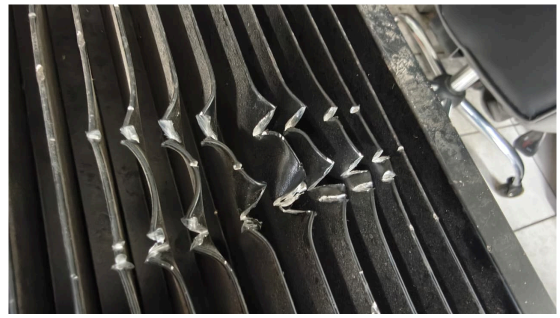

Figure 15.Results of the tests on an aluminium grating using the axe blade.

Furthermore, multiple deep cuts were made on an aluminium grating using the axe cutting edge, without any appreciable degradation in edge quality.

Figure 16. Cutting test results on a CF3M steel pipe.

It was also tested with a steel pipe, and showed a good performance against it, making a deep cut into it.

Conclusions.

This project allowed us to integrate both our theoretical and practical knowledge related to our engineering field, especially in design, the selection of CA40 martensitic stainless steel due to its suitable properties, as well as the implementation of feeding system designs to minimize casting defects.

During the mechanical testing of our axe, we verified that it possesses the desired mechanical properties. This is because it was subjected to a quenching process, thereby increasing its impact resistance.

By performing the analysis of dimensions, volume, and material distribution, we were able to confirm that the design provides adequate strength and good stability during use.

Thus, it is confirmed that the selected casting process facilitates the production of a solid piece without defects that could compromise its mechanical performance.

Additionally, the incorporation of the pony silhouette on the axe blade is not merely a decorative detail, but rather a symbolic representation as part of the team's identity, referencing our institution's mascot. Its inclusion adds a distinctive value that complements both the technical design and the overall meaning of the work carried out.

Special thanks.

The Pony’s Foundries Team expresses its sincere appreciation to the organizations and individuals whose support was essential to the successful completion of this project. We would like to thank the team at Fundidora Morelia for their technical expertise, continuous support, and access to facilities throughout the casting and manufacturing stages, with special recognition to Ing. Uriel Hernández Chávez and the foundry personnel for their direct involvement and guidance.

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References.

[1] “Arms and Armor Horseman’s Axe,” Tritonworks. [Online]. Available: https://tritonworks.com/horsemans-axe/. Accessed: Nov. 19, 2025. :contentReference[oaicite:0]{index=0}

[2] “Battle of Bannockburn,” Wikipedia. [Online]. Available: https://en.wikipedia.org/wiki/Battle_of_Bannockburn. Accessed: Nov. 19, 2025.

[3] “Horseman’s Ax of Cardinal Ippolito de’ Medici (1511–1535),” *The Metropolitan Museum of Art*. [Online]. Available: https://www.metmuseum.org/art/collection/search/26548. Accessed: Nov. 19, 2025. :contentReference[oaicite:0]{index=0}

[4] “Fleur-de-lis,” Britannica, https://www.britannica.com/topic/fleur-de-lis. Accessed: Nov. 19, 2025.

[5] R. Fisher, “¿Qué es la Fundición en Arena?,” *Reliance Foundry*, Aug. 9, 2023. [Online]. Available: https://www.reliance-foundry.com/blog/fundicion-en-arena-es?srsltid=AfmBOopZl0ZWmccl2-9iJ3CSzZBHMTNi4rsXr96Oi2WTAGsq_5P6XNQy. Accessed: Nov. 19, 2025. :contentReference[oaicite:0]{index=0}

[6] C. McCaul, “Keep the Wear Out of Pump Wear Rings,” *Chemical Engineering*, vol. 96, no. 10, p. 149, 1989.

[7] Ju Feng Special Steel Co., Ltd., “ASTM-CA-40 | Resultado de consulta de base de datos de acero,” JFS Steel. [En línea]. Disponible: ASTM-CA-40 A743. [Accedido: 19-mar-2026].