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

Texas State University - Axe Cats

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Abstract

This project was completed as part of the Steel Founders' Society of America (SFSA) Cast in Steel 2026 Competition, which challenges students to design and manufacture a functional steel casting. Texas State University's "Axe Cats" team developed a horseman's axe inspired by Nadir Shah's Indo-Persian battle axe. The design process incorporated historical research, CAD modeling, and casting simulations to optimize the axe's geometry, gating systems, and material selection. The axe head was cast using no-bake sand with 5160 steel and aluminum components were incorporated to meet competition weight constraints. Multiple casting methods were evaluated, and design modifications were made based on simulation results to reduce defects such as porosity. The team encountered challenges during manufacturing, including defects from an interrupted pour, requiring design adjustments and process modifications. This report outlines the design decisions, manufacturing processes, and evaluation methods used to produce a functional horseman's axe.

1 Introduction

SFSA created the Cast in Steel competition to encourage students to learn about the casting process of steel products by applying the latest technology available. For the 2026 competition, we were challenged to produce a functional horseman's axe that demonstrates both engineering knowledge and manufacturing capability.

Our goal for this project was to design an axe inspired by the Indo-Persian weapon carried by Nadir Shah, all while applying modern engineering and casting techniques. To meet this goal, we combined historical research with CAD modeling, material selection, casting simulations, and manufacturing processes. Throughout the design process, we evaluated multiple approaches to the shape of our axe and its manufacturing. While some casting methods and design choices would have simplified the process, we intentionally explored more complex options in order to better understand casting dynamics and challenge ourselves as engineers. This included comparing casting methods, refining gating system designs, making repeated changes based on simulation results, and evaluating methods for fastening the axe head to the haft.

In this report, we present our research, conceptual design process, material and process selection, manufacturing procedures, and testing approach used to produce our axe.

2 Historical Background

2.1 Origin of Axe

Our axe design was inspired by Nadir Shah, founder of the Afsharid Dynasty in Iran. Nadir first emerged as a military commander from the Afshar tribe, fighting against the Ozbegs (Iran Chamber Society, 2025). After the Safavid dynasty was overthrown in 1719, he offered his services to the Safavid heir, Tamsap II, to help restore Persian rule (Iran Chamber Society, 2025). Through a series of battles, Nadir had restored Persian control from the Afghans in 1729 (Iran Chamber Society, 2025). He was considered Persia's most gifted military genius, and in 1736, he deposed Tamsap II and took the throne as Iran's Shah (Iran Chamber Society, 2025). He established the Afsharid dynasty in his name and used his power to invade India, seizing New Delhi (Iran Chamber Society, 2025). Historical accounts document his use of a battle axe during his invasion (Durand, 1908). He had carried it through all his battles, giving him the name 'The Lord of the Axe' (Durand, 1908). The creator of the axe is unknown, but it's predicted that the axe was produced in New Delhi, India. Our mission will be to replicate the Indo-Persian craftsmanship of Nadir's axe.

2.2 Characteristics of an Indo-Persian Axe

Most battle axes have small heads with a secondary weapon at the butt of the axe (Forde, 2023). Common secondary weapons include a hammer, a beak, or a spike (Forde, 2023). There were seven axe forms seen in India during the Mughal period: Khond, Qajar Revival, Antelope, Bhuj, Farsa, South Indian, Tabarzin, and Zangal (Forde, 2023). Specifically, the Qajar Revival style and the Tabrzin style are considered Indo-Persian axes (Forde, 2023).

The Qajar style is associated with the Qajar Period of Iran and later made its way to India (Forde, 2023). These axes featured a crescent-shaped head made of crucible steel, and some styles even incorporated gold and silver inlays (Forde, 2023). The Tabarzin style is known as a traditional battle with Persian origins and was made with a wedge-shaped head (Forde, 2023). Like the Qajar styles, Tabarzins were also decorated with unique designs using silver and gold (Forde, 2023). Tarbarzin axes were designed to be used by horsemen, which gave them the alternate name “saddle axe” (Forde, 2023).

Our axe will resemble Nadir Shah’s battle axe, which was created with a blend of Indian and Persian artistic styles (see Appendix A). The entire piece was fabricated using crucible steel, a material commonly used in Indian axes (Forde, 2023). The axe head is inscribed with Quranic verses and Nadir’s name and title in the Persian language, while its octagonal handle features decorative floral and creeper designs in the teh-nishan style (Google Arts & Culture).

3 Conceptual Design

3.1 Concept Selection

While researching for our concept and design selection, we learned the purpose of each component of an axe and what different styles would offer. Basing our choices off of the three key factors of functionality, uniqueness, and historical accuracy, we ended up with our final concept selection. Although Nadir Shah's battle axe is a wedge shape, we chose the crescent axe head shape because we found that crescent-shaped axes were also used in the Indo-Persian era and would provide better functionality for us in the competition (Royal Armouries Museum, n.d.). Crescent-shaped axes have better cutting efficiency and are much more forgiving on angled swings (Atkins, 2006).This not only helps us as a non-experts in axe swinging, but also works well for horsemen who are riding in the midst of battle on uneven terrain at high speeds. For our haft, we wanted to match the shape of Nadir Shah's due to its uniqueness and nice aesthetic. Although materials were not confirmed at the time, we knew we wanted something close to that octagonal shape. As for the handle, we wanted to cast it. We knew that we would have to go narrow with the haft if a metal was chosen due to weight restrictions. Having a thicker oval-shaped handle would be the best for functionality of the axe, allowing for better grip. We were aware of the challenges that came with this concept design, specifically the fastening of the axe head and the weight restriction, but we knew that if we could build the axe that we envisioned, it would be our best work entering the competition.

3.2 Material Selection

With a concept selected for our design, the next step was to finalize what materials will be used to create our axe. We wanted our battle axe to have the best properties possible while still resembling our historical model. The first thought was to cast the full axe piece by piece, from the handle to the haft and axe head, with 5160 steel. However, the weight of the axe would exceed the limit of the competition if we did that. Keeping 5160 steel as the alloy for the axe head, we concluded that we should outsource the haft, but rather than going for a more common wood option, a metal one would better suit our needs. Nadir Shah's axe is fully metal and we felt this would give us a good chance to get creative with the resemblance. After doing some research we found hex tubing in 6061 aluminum. Both the aluminum and the tubing gave us a chance to keep the weight lower than a fully steel cast haft, while still giving us the metal finish and strength we were looking for.

3.3 Engineering Simulations & Design Changes

The two main software programs used to develop the axe head and handle were OnShape and Inspire Cast. The CAD designs were created with the intention of keeping the originally chosen concept's features intact while also taking the weight limit into consideration. The head was made with three extrusions: the spike, the extrusion where the haft inserts, and the blade itself. This design ensured that each feature could be designed and optimized separately. The thickness of the axe blade and spike were reduced to a quarter of an inch to ensure they were not too thin for the casting mold. The extrusion for the haft was drafted to reduce weight and allow easier removal of the pattern from the sand when making the mold. The hollow portion was extruded to be 0.003in smaller than the diameter of the haft when accounting for steel shrinkage of around 2% to allow for an interference fit with the haft.

The gating system for the axe head was first calculated using various gating calculations to determine the choke area and effective height. The design features two gates that connect to the outside of the handle insertion area, meaning that a half-step reduction in diameter was required between the gates. Running the initial gating design through Inspire Cast showed that the design functioned in the software but was not practical for the test pour with aluminum, as the choke and ingate areas were too small. The overall design was retained but scaled up, with only the sprue effective height being kept the same. It is imperative that the molten metal does not exceed 1 m/s during pouring to prevent turbulence, which can create air pockets and lead to porosity in the finished cast. To account for the increased area of the gates and sprue, the choke area was decreased to 0.25 inches in diameter to ensure the gating would still be feasible for the actual pour. Finally, a large 4 inch riser was added to the middle extrusion of the axe head because, as the Inspire Cast simulation revealed, the last part to solidify was where the handle inserts, always leading to porosity in the final product. To finish the axe head, a core and core box was created to form the haft insertion area during casting (see Appendix B).

The handle was similarly made with three extrusions: the grip, which was extruded 5 inches in length and made elliptical for a more comfortable feeling in the hands, as well as two extrusions serving as guards. The handle was also hollowed out and its opening made 0.003in smaller than the haft diameter for the interference fit with the haft. Due to the elliptical shape of the handle and the hexagonal shape of the haft, the openings of the head and handle were carefully lined up accordingly.

Running the casting simulation on the handle proved to be a much simpler task than anticipated, as the simulation provided a good flow velocity, no cold shuts or major microporosity. Using what was learned in the casting simulation for the axe head, a large riser was added near the base of the handle, close to the ingate. Doing this led to the same desired result of all porosity being in the riser instead of the handle. A core and core box were then made for the handle's casting (see Appendix C).

4 Melting and Casting Process

4.1 Head Formation

The casting of the axe head was done using no-bake sand. After making a matchplate, three molds were produced due to the quick no-bake molding process, producing three potential axe heads to choose from. The molds were then sprayed with zircon to help create a smooth surface finish. During the pouring of the steel at 3125 degrees Fahrenheit, the bottom of the ladle burst, leading to a rush to finish the pour. As a result, two of the castings were unfortunately full of porosity, making them unusable.

We heat treated the steel to help distribute the alloying elements throughout the material. First, we normalized the axe head to create a uniform microstructure as a starting point for the heat treatment. We heated the furnace to 850°C and then placed the axe head inside to heat for 45 minutes. After, we allowed the steel to cool overnight to austenitize.

The next day, we reheated the furnace to 820°C and warmed the quenching oil to 49°C. Once the axe head had been heated for an hour, we quenched it in the oil, swirling it until the oil temperature dropped below 49°C.

4.2 Handle Formation

To maximize flexibility in our configuration and take advantage of aluminum's significant castability over steel, we used green sand to cast the grip of our handle. The aluminum hex bar used for the haft was 3ft long, and we used this material to create a custom flask as an experiment to cast the handle. This flask featured an opening where the aluminum haft would be inserted into the mold, acting as the core itself while molten aluminium was cast around it. This experiment turned out very well, and the attachment was solid, so it was the one chosen for the final product.

5 Non-Destructive Testing

For our non-destructive testing, all the teams from our university got to partner with Southwest Research Institute down in San Antonio, Texas. They have facilities and experts whose sole purpose is to conduct non-destructive testing, so their insight on how our axe heads should be treated moving forward was very helpful. We used one of their smaller X-ray machines, as our axe heads had less than 3” thick cross sections at any given point. This made the set up time much faster and the image capture process less time consuming. When the images were fully processed, the main things we were looking for were linear indications for defects and porosity. For the linear indications, if they were visible on the X-ray but not to the naked eye, a red dye penetration test would be required to unveil them and identify their severity. As for the porosity, there wasn't much to do other than see how much of it was present.

Unfortunately, for our team's axe, there was a substantial amount of both regular porosity and wormhole porosity (see Appendix D). We concluded that the gas content of the metal in its liquid form increased as we poured the metal. The Axe head on the right was from a different team that poured into their mold first, and there were about 6 molds poured between theirs and ours, with each axe head showing an increase in porosity. Our main focus then was to conduct an effective heat treatment process and sharpen our design to help recover the properties that were lost as much as possible.

6 Conclusion

Throughout this project, we successfully designed and manufactured a horseman's axe that combined our historical inspiration with modern casting techniques. We faced several challenges, particularly in the casting design and manufacturing process. There were times when a simpler process or design choice could have reduced risk, but we chose to pursue the more complex design to further challenge ourselves. We encountered issues such as porosity and defects from an interrupted pour, which required us to adapt and improve our approach.

These challenges ultimately strengthened our understanding of casting design, gating systems, and material behavior. Our final axe meets the competition requirements for functionality, dimensions, and materials, with a final length of 20 inches and a final weight of 2.65 lbs. Overall, this project allowed us to apply classroom knowledge to a real world application, while gaining valuable hands-on experience in metal casting.

References

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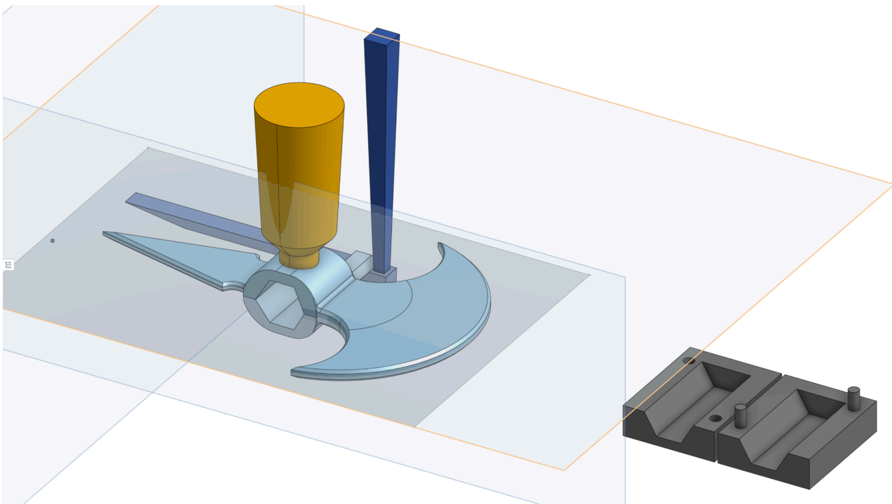
Appendix

Appendix A

Nadir Shah's Battle Axe at the National Museum, New Delhi

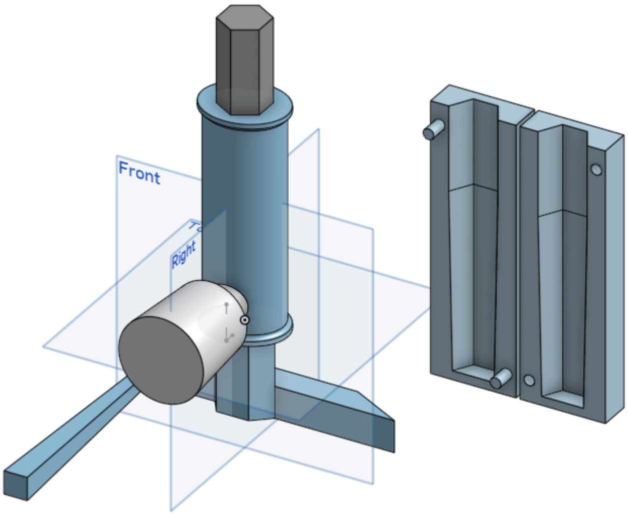
Appendix B

The Axe Head with Gating System, Core, and Core Box



Appendix C

The Handle with the Gating System, Core and Core Box



Appendix D

X-Ray Scan of our Horseman's Axe (Left)