

SFSA CAST IN STEEL 2026

Horseman's Axe

University of Wisconsin-Platteville



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Executive Summary

The Steel Founders' Society of America (SFSA) has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. This project focuses on the design and production of a historically inspired horseman's axe using advanced casting and manufacturing techniques.

The selected design is primarily based on the Arabic Tabar and Tabarzin, which were widely used by mounted warriors in the medieval Islamic world. These axes were characterized by lightweight construction, a curved cutting edge, and an emphasis on maneuverability, making them effective for one-handed use on horseback. Our axe reflects these features through its thin, wide blade and balance. The final product shows strong historical accuracy with many ties to the early Arabic Tabar.

Casting technology was used extensively to add value to the final product. A semi-centrifugal casting method was developed using a modified lathe system, allowing molten metal to be distributed more effectively into thin sections of the mold. This approach improved mold filling, reduced defects such as misruns and shrinkage, and promoted a finer grain structure due to directional solidification. Compared to traditional static investment casting, this method enabled the production of a near-net shape axe head, minimizing the need for excessive machining and material removal while improving mechanical performance.

The design process involved multiple iterations to balance performance, manufacturability, and historical accuracy. Early CAD models focused on blade geometry and spike proportion, followed by gating and feeding system optimization to ensure proper metal flow. Some challenges faced such as section filling and stress concentration were addressed through the use of internal chambers and controlled transitions in geometry. The handle design also evolved significantly, shifting from a heavier solid concept to a machined, skeletonized 6061 aluminum structure to improve balance and handling.

Non-destructive testing methods were used to make sure the axe was sound. Visual inspection was used throughout the process to check for surface defects, and the casting design itself helped limit internal flaws. Material composition was verified using spectrometry, and consistent heat treatments helped ensure the properties were consistent.

The final axe meets contest requirements for size, weight, and material composition. The axe head was cast using a modified AISI 5160 steel alloy, selected for its combination of toughness and hardenability. The handle was machined from 6061 aluminum to reduce overall weight while maintaining strength. The completed axe achieves the required dimensions and demonstrates both functional performance and historical authenticity.

Overall, this project successfully integrates historical design, modern casting techniques, and material engineering to produce a high-quality horseman's axe that meets both the technical and competitive objectives of the Cast in Steel competition.

Literature Review

Origins of the Horseman's Axe

As mounted warfare became the dominant mode of combat from the medieval period onward; weapons evolved to meet its **demands**. The horseman's axe emerged as a specialized tool designed for one-handed use, allowing combatants to maintain control of their mounts while delivering powerful, concentrated strikes. Its versatility and compact size made it an effective **complement** alongside other mounted weapons such as swords, lances, and maces.

While horseman's axes appear across a wide geographic range, this section will focus on Arabic and Middle Eastern variants, specifically those associated with Islamic military traditions. In Arabic contexts, these weapons are often discussed alongside related forms such as the Tabar and Tabarzin, though terminology and classification can vary across regions and historical sources. By narrowing the scope to Arabic examples, the aim of this review is to highlight both functional characteristics and cultural significance within a more defined historical **lens**.

The development of the Tabar is closely tied to the emergence of Islamic cavalry forces from the early medieval period onward. As Islamic empires expanded across the Middle East and North Africa, they encountered and incorporated military traditions from Persian, Byzantine, and Central Asian cultures. This exchange not only influenced battlefield practices but shaped the cultural and symbolic meanings attached to weapons within the Islamic world.

During the medieval period, in particular the Abbasid and Mamluk regimes, cavalry units were the backbone of a military strategy which emphasized flexibility and versatility in combat. Within these units, axes served as important secondary weapons. Arabic Tabarzin are typically characterized by lightweight, relatively small heads and elongated handles which enabled greater agility from horseback. The cutting edge often featured a curved profile. In contrast to heavier infantry axes, the Tabar prioritized maneuverability and speed. While these features largely reflect practical conditions, they also contributed to the weapon's very important visual identity. These weapons were deeply embedded within a broader culture that emphasized skill, discipline, and hierarchy.



Figure 1 Folio from Firdausi's Shahnameh

This cultural significance is extensively highlighted in the literary and artistic traditions of the era, where weapons are often portrayed as an extension of a warrior's identity rather than a mere tool. The Tabarzin frequently appears in manuscripts and art, symbolizing strength, decisiveness, and resolve. Descriptions of the Tabar in literature make constant reference to the craftsmanship, material quality, and ornamentation as a means to declare the user's status.

At the dusk of the Mamluk empire, the influence of neighboring regions on the design of the Tabar became increasingly apparent. It is around this time that regional trends began to refine the design of the Arabic horseman's axes. This is reflected in the adoption of more refined blade shapes and decorative techniques, including inlaid metals and engraved inscriptions. This increasing emphasis on decoration highlights the growing importance of these weapons as cultural artifacts as well as functional objects.



Figure 2 Persian Horseman's Axe (MET)

As firearms gradually reshaped war from the 16th century onward, the practical role of the horseman's axe began to decline. However, similar to many traditional weapons in the Arab world and beyond, it did not disappear. It evolved into exclusively a symbol of status and authority. Often carried in ceremonial contexts. This transition reflects a broader shift in martial culture around the turn of the century where many weapons came to embody ideals of heritage, cultural identity, and personal expression.

Metallurgy

Mechanical Properties

Mechanical properties play a critical role in determining the performance of UW Platteville's axe, particularly with respect to impact resistance, edge retention, and resistance to failure during testing. Unlike a blade designed primarily for cutting and axe is subjected to repeated shock loading and high impact forces, making toughness and durability just as important as hardness.

Hardenability refers to the ability of steel to form martensite during cooling and is influenced by both carbon content and alloying elements. For an axe head, sufficient hardenability is necessary to ensure the cutting edge achieves a martensitic structure during quenching. However, full through-hardening of the head is not desirable, as it would increase brittleness and susceptibility to fracture. A combination of a hardened edge and a tougher, more ductile core is preferential to absorb impact energy without catastrophic failure. This was achieved through highly controlled heat treatment and care.

Toughness is the ability of a material to absorb energy prior to fracture and during testing the axe experiences repeated loading, which can and will initiate and propagate cracks if the material is insufficiently tough. A properly tempered microstructure allows the axe to withstand repeated impacts without cracking or breaking by reducing brittleness while maintaining adequate strength.

Based on the requirements outlined, material selection must prioritize high toughness in combination with sufficient hardness at the cutting edge. AISI 5160 is a suitable choice due to its chromium content which improves hardenability and its ability to achieve a good balance of strength and toughness after heat treatment.

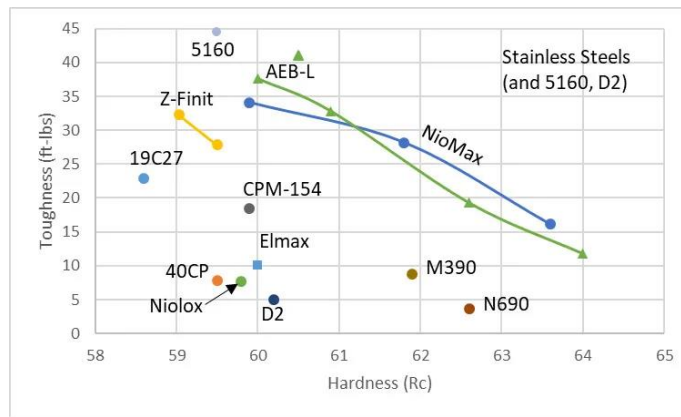


Figure 3 Plot of hardness and toughness of various steels

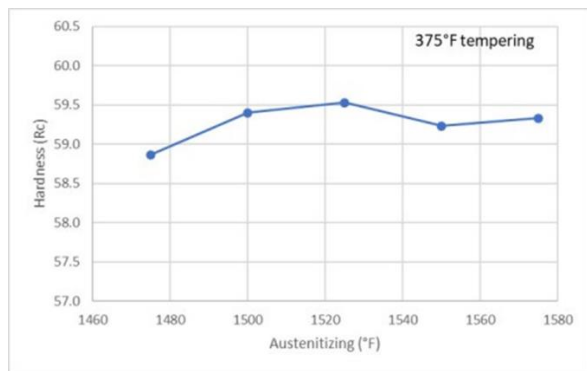


Figure 4 Hardness vs. Austenization temperature (Larrin)

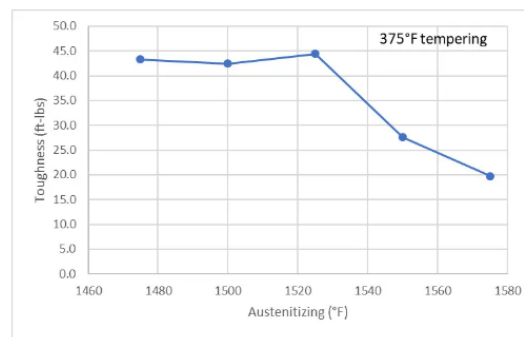


Figure 5 Toughness vs. Austenitizing Temperature (Larrin)

Chemical Properties

Figure 10 presents the baseline AISI composition used as the reference alloy. While the figure below shows the modified composition developed for this axe. The base steel was selected using the criteria outlined above, then slightly modified to better meet the team's desired applications. The sulfur content was reduced from 0.04% to 0.005% to improve metal cleanliness and reduce the presence of nonmetallic inclusions that can act as crack initiation and propagation sites. Chromium content was increased from 0.9% to 1.003% to improve hardenability. Nickel was added to enhance toughness.

Component Elements Properties	Metric
Carbon, C	0.56 - 0.64 %
Chromium, Cr	0.70 - 0.90 %
Iron, Fe	97.085 - 97.84 %
Manganese, Mn	0.75 - 1.0 %
Phosphorus, P	<= 0.035 %
Silicon, Si	0.15 - 0.30 %
Sulfur, S	<= 0.040 %

Figure 6 AISI 5160 Steel Composition(Matweb)

C	Si	P	Mn	S	Mg	Cr	Cu	V	Ce	Nb	Al	Mo	Ni	Ti
0.603%	0.289%	0.019%	1.05%	0.005%	0.00%	1.003%	0.107%	0.009%	0.008%	0.002%	0.085%	0.023%	0.530%	0.029%

Figure 7 UWP Modified 5160 Composition

Process

After evaluating several axe geometries, the team chose a design inspired by a Tabar style axe due to its combination of a wide cutting edge and thin casting profile. The curved blade and reinforced central section provided a good balance between performance and durability. The CAD model shown in Figure 8 was the result of many renditions. Finding a good balance between the pick on the back and blade on the front was crucial in creating this axe head.

One of the primary challenges was achieving proper filling on the thin profile of the axe head. The idea was that the thinner the axe head could be cast, the less finishing and grinding down of the cast would have to be done. This is where the semi-centrifugal caster was born. This idea also allowed for not only thinner cast axe heads, but centrifugal casting also gives the benefit of producing a fine grain structure due to rapid cooling and directional solidification, which significantly enhances the mechanical properties of the cast materials.

Figure 3 Axe Head with Gating System

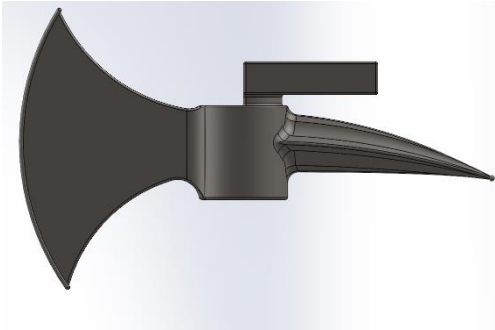


Figure 8

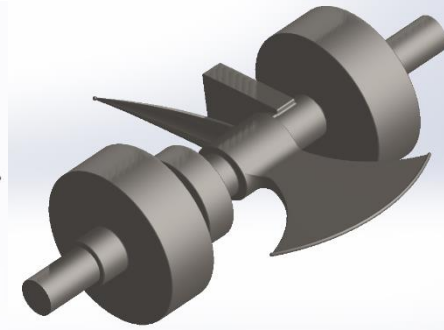


Figure 9

The wide and thin blade profile also created concerns with uneven metal flow. As shown in Figure 13 the gating system was designed to direct metal into the chambers first, allowing it to feed into the blade. A semi-centrifugal casting method was used to help distribute the molten metal more evenly across the geometry.

Attention was also given to transitions between the blade, body, and eye to reduce shrinkage and stress concentrations. Smooth fillets and gradual changes in section thickness improved both flow and solidification behavior. The final design aimed to remain near-net shape while still pushing thinner sections to improve cutting performance.

Semi-Centrifugal Casting Method

To produce the primary axe head castings, a semi-centrifugal casting setup was developed using a modified lathe system. The ceramic shell mold, shown in Figure 10, was designed with the internal chambers to help capture slag and promote more uniform metal distribution throughout the casting.

Figure 10 Axe Head Ceramic Shell



The system was built around a ~1915 Rockford lathe sourced from Facebook Marketplace. A 5 HP motor paired with a variable frequency drive was installed to provide sufficient torque and speed control. The lathe shown in Figure 11 had the gearbox disconnected in favor of the more controllable VFD.



Figure 11



Figure 12

Custom wedge supports were mounted on either side of the lathe to securely hold a cylindrical container housing which contained the ceramic shell mold, filled in with plaster. The wedges on bearings shown in Figure 12 hold the large steel cylinder in place once pressed together.

Once mounted, the mold assembly rotated at approximately 1200 RPM. Molten metal was then introduced into the spinning mold through a side-entry sprue also known as the “Raygun”. The Raygun shown in Figure 17 was made from fiberglass reinforced ceramic shell. It was placed on the tailstock and slowly brought in until it was inside the first chamber. The metal is then poured into the first chamber of the ceramic mold where it feeds in. This semi-centrifugal approach used rotational force to drive the metal outward, improving fill along thinner sections and reducing the likelihood of defects such as hot tears or underfilling.

The internal chamber design played a key role in this process by trapping slag and smoothing the flow of metal as it progressed through



the mold. This helped ensure more consistent filling across the full geometry of the axe head, particularly along the wide blade. While

this was the primary casting method used, several axe heads were also produced using traditional static investment casting in ceramic shell molds. These molds shown in Figure 18 were designed with 4 axe heads per mold. These were used as backups and for testing.

Heat Treatment

The heat treatment began by normalizing the axe heads at 1600 °F for 1 hour 45 minutes to refine grain structure and improve machinability. After machining, a second 45-minute normalizing cycle relieved residual stresses. The parts were then austenitized at 1525 °F for 45 minutes and quenched in soybean oil. Finally, the axes were tempered twice at 375°F—first for 45 minutes, then for 1 hour 30 minutes—to transform retained austenite into martensite and fully temper it.

Grinding/Polishing

For the post processing of our axe head, we started by using various grit grinding wheels in a 2" die grinder in addition to dual action sanding from 120-1500 grit. Furthermore, tools including air band files, mini dual action polishers, 5" & 6" Dual action sanders and jewelers dremel tool were utilized. After grinding/ sanding, a diamond compound and polishing oil were used to achieve the final shine. For the handle, a mini dual action polisher was utilized up to a 1500 grit, in addition to a diamond polishing compound.

Handle

Design

The original handle concept was inspired by traditional Tabar-style axes, which often use an all-metal construction. Early in the design process material ideas included wood, carbon fiber, rattan, and many solid metals, but weight quickly became the most important factor. For a horseman's axe, a lighter handle improves control, speed, and overall balance.

Magnesium was initially selected due to its low density and high strength-to-weight ratio, with plans to cast the handle. However, challenges associated with casting magnesium, along with difficulty sourcing a suitable alloy for the handle, made this approach impractical. The design direction was then shifted toward a fully machined handle.

Two primary handle designs were developed during this process. The first design, shown in Figure 19 focused on a more solid and flowing geometry, prioritizing strength but resulting in quite a bit of excess weight. While functional, it did not meet the performance goals for balance and control that we wanted to achieve. The decision to move away from casting the handle influenced the decision to create a new similar design.



Figure 19 Original Axe Handle Design

The second design shown in Figure 20 introduced a slimmer, skeletonized structure to significantly reduce mass while maintaining



sufficient strength. Material was removed, a drill in the center of the axe, and a slight curvature was incorporated to improve ergonomics and handling. This curved profile allows for a more natural grip and better swing control.

6061 aluminum bar stock was selected for its combination of machinability, strength, and relatively low weight. The final design was refined to simplify manufacturing while achieving the desired balance between durability and weight reduction. After machining, the handle was sanded and polished to achieve a smooth finish. As shown in Figure 21, the final product turned out clean and well-balanced, with a comfortable feel in hand.



Figure 17 Machined Axe Handle

Data/Results

This section presents the mechanical and material data of the 5160-steel used in the axe. Tests performed include tensile testing, Jominy hardenability, hardness (HRC) profiling from the cutting edge to the body, spectrometer analysis, and microstructural examination.

AISI 5160 Steel, normalized 855°C (1570°F)			
Categories: Metal; Ferrous Metal; Alloy Steel; AISI 5000 Series Steel; Low Alloy Steel; Carbon Steel; High Carbon Steel			
Material Notes: Contains a medium-to-high level of carbon. It is directly hardenable to medium hardness. Used for applications with smallish cross sections in severe service, notably automotive leaf springs and other spring and fastener uses.			
Key Words: SAE J770, UNS G51600, ASTM A322, ASTM A331, ASTM A505, ASTM A519, ASTM A519, SAE J404, SAE J412			
Vendors: No vendors are listed for this material. Please click here if you are a supplier and would like information on how to add your listing to this material.			
Printer friendly version Download as PDF Download to Excel (requires Excel and Windows) Export data to your CADFFEA program			
Add to Folder: <input type="checkbox"/> My Folder 0/0			
Physical Properties	Metric	English	Comments
Density	7.85 g/cc	0.284 lb/in ³	
Mechanical Properties	Metric	English	Comments
Hardness, Brinell	269	269	
Hardness, Knoop	294	294	Converted from Brinell
Hardness, Rockwell B	99	99	Converted from Brinell
Hardness, Rockwell C	27	27	Converted from Brinell
Hardness, Vickers	264	264	Converted from Brinell
Tensile Strength, Ultimate	958 MPa	139000 psi	
Tensile Strength, Yield	530 MPa	76900 psi	
Elongation at Break	17.5 %	17.5 %	in 50mm.
Modulus of Elasticity	205 GPa	29700 ksi	Typical for steel
Bulk Modulus	160 GPa	23200 ksi	Typical for steel
Poissons Ratio	0.29	0.29	Calculated
Machinability	55 %	55 %	spheroidized annealed and cold drawn. Based on 100% machinability for AISI 1212 steel.
Shear Modulus	80.0 GPa	11600 ksi	Typical for steels.
Izod Impact	11.0 J	8.11 ft-lb	

Figure 21 MatWeb data for normalized 5160 steel

Tensile Test

A tensile test was performed on a test bar poured in the same heat as the team's submitted axe to evaluate its mechanical properties. The stress-strain graph for the 5160 steel indicates a combination of high strength and good ductility. The material exhibits a clear elastic region followed by yielding and continues through a region of plastic deformation with noticeable strain hardening until reaching an ultimate tensile strength of 156,000 psi. The gradual slope beyond the yield point and the extent of elongation before fracture suggest that the material is capable of absorbing significant energy without sudden failure. This behavior is consistent with a material that provides both durability and impact resistance, both desired characteristics for performance during testing.

Hardness

Hardness tests (HRC) were performed from the cutting edge to the body of the axe to evaluate the variation in hardness across the material. The measured hardness values indicate 53 HRC at the cutting edge and gradually change to 28.5 toward the body, as shown in the data below. The hardness values indicate that the axe has a hard cutting edge and a tougher, less brittle body. Specifically, the higher HRC at the edge suggests it can maintain a sharp edge and resist wear during cutting, while the lower hardness toward the body provides the necessary toughness to absorb impact and prevent cracking or chipping during use. This gradient in hardness is typical of a well-tempered axe which balances edge retention with overall durability and toughness.

Jominy End Quench Test

Distance from quenched surface (in)	Hardness (HRC)		Test Results
	Max	Min	
0.0625	-	60	60
0.125	-	60	61.5
0.1875	-	60	63.5
0.25	65	59	65
0.3125	65	58	64.5
0.375	64	56	62.5
0.4375	64	52	63
0.5	63	47	62.5
0.5625	52	42	59
0.625	61	39	62
0.6875	60	37	61
0.75	59	36	60
0.8125	58	35	58.5

0.875	56	35	55
0.9375	54	34	58

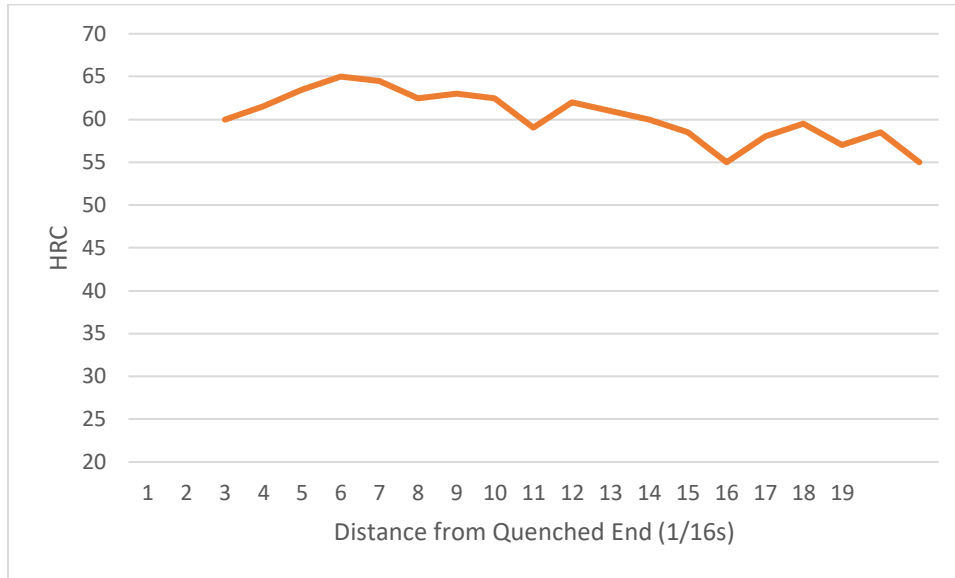


Figure 19 UW Platteville Jominy Results

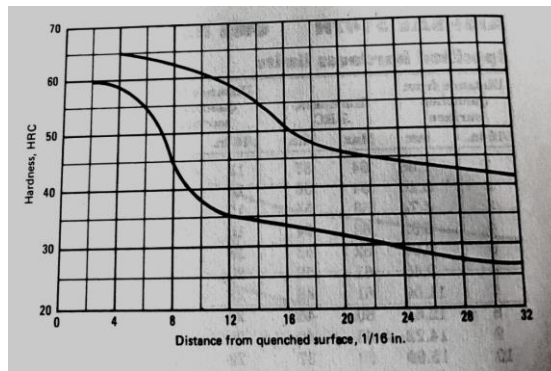


Figure 20 5160 Jominy Results from Literature

Spectrometer

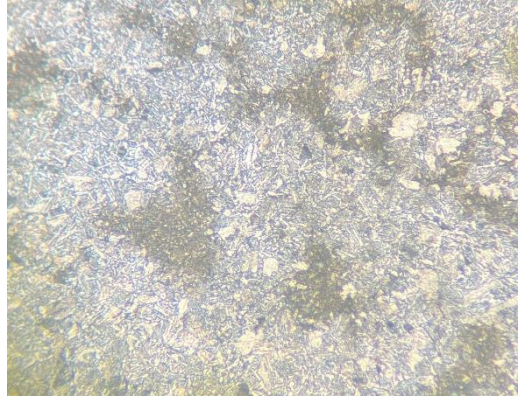
The elemental composition of a sample from the static heat was analyzed using a Bruker Q4 Tasman. Prior to testing, the instrument was calibrated according to manufacturer specifications to ensure accuracy. Composition values are presented in the table below.

		C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al
Target Composition	Max	0.64	0.3	1	≤ 0.035	≤ 0.04	1	0.025	0.55	≤ 0.011	≤ 0.01
	Min	0.58	0.2	0.75			0.8	0.02	0.5		
Sample 1 Composition		0.604	0.287	0.835	0.018	0.012	0.752	0.026	0.031	0.096	0.0086
Sample 2 Composition		0.621	0.273	0.837	0.025	0.014	0.076	0.024	0.029	0.098	0.0053

Figure 22 UWP modified 5160 Final Composition

Microstructural Analysis

The microstructural examination of the 5160 steel reveals an untempered martensitic matrix. This structure is responsible for the high hardness observed at the cutting edge but also will contribute to brittleness in the material before tempering. Understanding this matrix is important, as subsequent tempering will reduce brittleness while maintaining sufficient hardness for the axe's performance. As-cast microstructure is shown in the figure below.



Conclusion

Despite production challenges, a near net casting within the required weight and size was successfully processed, and heat treated to yield a historically accurate, functional, and aesthetically pleasing horseman's axe.

Mechanical, chemical, and metallurgical constraints were met as intended from results.

Many of our capabilities were pushed in this project, including our casting and machining capabilities

Works Cited

[A glossary of the construction, decoration and use of arms and armor](#)