

SFSA Cast In Steel 2026 - Horseman's Axe

Technical Report

Cal Poly Pomona - The Incrucibles



Cal Poly Pomona



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1. Introduction

1.1 Project Objective and Historical Context

SFSA has created this competition to encourage students to learn about making steel products using casting processes and applying the latest technology available. The 2026 Cast in Steel competition aims at the design and manufacture of a horseman's axe. Students must document the project in a technical report, create a project video, and manufacture a steel casting of the axe. The team will be advised by university faculty, and work with a foundry partner familiar with steel castings. The axe will weigh no more than 1.5 kg (3.3 lbs.) and will be no longer than 800 mm (31.5 in).

As armor technology improved during the 14th century, specifically the development of stronger plate armor, many weapons such as swords and blunt concussive weapons became less effective because their strikes would often slide off armored surfaces. This shift in battlefield protection led to the development and increased use of axes, which became important weapons due to their concentrated striking force that was better suited for damaging or penetrating heavy armor. One variation that emerged from this period was the horseman's axe, which was designed for mounted combat and allowed riders to deliver powerful strikes while maintaining mobility on horseback [1].

Over time, these axes evolved to be effective both in infantry and mounted combat, eventually becoming a common secondary weapon carried by noblemen alongside their swords [1]. While many horseman's axes were designed primarily for combat and armor penetration, others incorporated decorative features that reflected status and craftsmanship [2].

2. Research Phase

2.1 Axe Composition

The standard axe contains two main sections, the head and the handle, joined with wedges.

The first main section of an axe is the head, containing the blade, the eye, and the optional spike. An axe blade is composed of multiple sections itself to maximize both cutting and bludgeoning force. The horseman's axe is known for having a more concave, curved blade. These parts include the bit, edge, beard, cheek and back [3]. The bit is the primary cutting portion of the blade, which offers a balance between sharpness and thicker durability. The edge is the sharpened section of the blade which will cut into targets on impact. The beard is the lower side portion of the blade which assists with control and increases the cutting surface by extending the cutting edge. It is connected directly to the cheek of the blade, the surface area of the axe sides that disturbs force. Finally, the back of the blade is often modified to either be flat or include a second bit for extra damage. Moving on from the blade, the eye of the axe is an opening where the handle is inserted and tightly fit to the axe head. Additionally, a common rear feature of horseman's axes is the spike, giving the weapon additional flexibility in combat [3].

The second main section of an axe is the handle, which can be broken down into the grip, shoulder, and knob [3]. Longer handles can increase the leverage and striking power of the axe, but can be

cumbersome if too long. Horseman's axes have a handle of medium-length, balancing reach and control [2]. They come in various materials including different types of woods and metals, with the former often preferred due to improved shock absorption and replaceability. Metal handles do have the advantage of strength and durability, but can quickly wear out the user due to weight and excessive vibration [4]. The grip of the handle is the section where the axe is held. The shoulder is the transition area near the head that improves stability. Lastly, the knob at the end of the handle prevents the tool from slipping out of one's grip [5].

2.2 Materials

One of the major goals of this competition is to find a steel alloy that allows us to obtain desired properties in making a horseman's axe. This would require us to find an alloy that has good castability, balance between hardness and ductility, and heat treatability. Our research has led us into Carbon Steels, which is known for their high strength, durability, and versatility [6]. We narrowed down our carbon steel selections to those alloyed with Chromium and Molybdenum in the 41xx carbon steel family, known for their strength and strength-to-weight ratios [7]. We decided that a medium carbon steel would offer a good balance of strength and hardness, so our selections narrowed down to 4130 and 4140 carbon steel. Since we are targeting higher hardness, 4140 was selected.

4140 is known to perform well under extreme operation conditions before wear or failure. It has excellent tensile strength, strength-to-weight ratio, impact resistance, heat treatability, toughness, wear resistance, and dimensional stability. It is typically used for complex and durable components in the aerospace, defense, automotive, and motorsports industry as well as for industrial machinery [8].

There are a few selections of materials for the axe handle such as wood, steel, fiberglass, or plastic. Fiberglass handles are tough and strong while being light. They are also resistant to moisture and temperature. Although they are durable, they will break and are difficult to replace. Steel is another choice for axe handles. While they are tough and durable, they are heavy and will transfer shock to the user's hand. Since they are typically manufactured into the axe head, it cannot be replaced when broken. Plastic is also used for handles and are typically made from polypropylene or fiber reinforced nylon. They are light, weather resistant, and transmit shock well; however, they become brittle in the cold. Wood is the traditional choice of axe handles. They can be shaped and modified easily to fit the user and can produce a good looking handle when sanded, stained, and rubbed with oil. They are very easy to replace as well, though they may shrink or swell with changes to humidity[9].

Hickory is the top choice for axe handles, providing exceptional strength-to-weight ratio, shock absorption, and resistance to splitting. Ash is also a preferred alternative, lighter than hickory while still providing good durability and shock absorption. Maple and Birch are also good alternatives as they provide a balance of strength and flexibility. They provide excellent performances, but may require more maintenance. Identifying high-quality wood pieces is just as important. Wood pieces with straight, parallel grain lines are crucial for axe handles as irregular grain patterns produce weak points that can lead to failure. It is also important to select denser and harder woods to provide greater durability and resistance. It is also good to aim for woods with 12-15% moisture content to prevent warping and cracking [10]. Due to its traditional use and versatility, wood became our primary choice of material for the handle. Hickory or ash will be our preferred choice of wood, the other woods mentioned would work as well.

3. CAD Modeling

3.1 Initial Sketch

Our axe design was inspired by historical 15th–16th century German horseman’s axes and German Reiter axes, known for their curved blades and detailed engravings. We began with a hand-drawn concept based on our own ideas, which originally included a large top spike and straight rear spike. However, after group discussion, we removed the top spike, replaced the rear spike with a smaller axe form, and added a steel shoulder to better secure the head to the handle. We then refined the shape to improve balance, increased the thickness of the connector for strength, and smoothed it out to improve force distribution and reduce cracking as much as possible. As the design progressed into CAD models, we adjusted proportions and reduced weight while maintaining durability. To tie the theme together, we engraved a horse on the blade to represent both the historical horseman inspiration and our school mascot, the Broncos, creating our first design shown on Fig. 1.

3.2 Axe Head 1st Iteration

The initial CAD design was made by tracing the outline of the concept sketch. Simplifications and modifications were made on the blade portion to accommodate manufacturability. Changes from the sketch on the back were implemented for aesthetic purposes to bring in horse inspired design features. A major design concern addressed by this design was rounding off sharp corners on the axe body, as well as being overweight. These changes implemented for our 1st iteration are shown in Fig. 2. The consistent body thickness as well as the large overall size, 7in x 9in x 0.5in, allowed for this design revision to be grossly overweight at more than 4 pounds. Ultimately, this design neglected a few design constraints such as the weight limit and castability and was overhauled.

3.3 Axe Head 2nd Iteration

In order to save on weight the side profile was changed and both the tail and the blade were shortened. Additionally the blade was thinned and profiled along the sides to lessen weight while still being sufficiently large enough to accept a reasonably sized handle. The blade uses a flat 40 degree included bevel angle and has an arc length of 8 inches.. A target weight of 2.3 pounds was set to comfortably allow for the later manufacture of a wooden handle without going over the competition weight limit. The was adjusted and embellished to return a final simulated weight of 2.21 pounds with a thickness of 0.45 inches. The overall dimensions are 6.7in height x 8.25in length x 0.96in width. Additionally, this render shown in Fig. 3 includes our engraved embellishments as well as any fillets that would survive the grinding process.

3.4 Gating Design

After receiving approval from our foundry partner on our final design, we began working on our gating design. Our gating design would only include 1 axe head. Since our final axe would be investment casted, we would need to keep our gating system simple, avoid excessive turbulence, and keep our gates thick and support critical regions [11]. Given direction by our contact, we decided to place our gates on the top surface on the back of the axe head, as well as on the top of the blade region. For the gates, we

extruded them upward for $\frac{1}{4}$ inches before having them tapered by 30 degrees, then have gates go straight again and connected. The final result of the gating is shown in Fig. 4.

3.5 Handle Design

We designed our axe handle based on a standard curved axe handle. We started by importing an axe handle template onto SolidWorks and traced it out as shown in Fig. 5. We used this to model a thin stencil that we could 3D-print out and trace the axe handle shape onto the wood. We originally scaled the handle length to around 30 inches to maximize the axe length; however, upon running a test print of the axe handle, it was too long to utilize properly. We scaled the handle length down to around 20 inches as a result.

4. SolidCast Simulation

Simulations were conducted using SolidCast in conjunction with the development and design of our pattern in order to ensure the pattern would create a mechanically and dimensionally superior casting. Figure X shows solidification time simulation of our final pattern. Shown by Fig. 6, there were no cold shuts and there were proper directional solidification starting at the thinnest features such as the blade and spike and ending in the riser.

5. Production Phase

5.1 Foundry Overview and Casting Process

Our foundry, Aerotec Alloys located in Norwalk, California, specializes in investment casts for ferrous and non-ferrous metals. They specialize in parts for the aerospace, defense, maritime, automobile, and medical industries.

Investment casting, also known as lost wax casting, is a metalcasting process in which molten metal is poured into a ceramic mold. The process starts with a wax pattern being injection molded shaped as the final part. They are designed to reproduce millions of wax parts. The wax patterns are then glued onto a wax runner system called a “tree”. The wax tree is then dipped into a ceramic slurry and covered in sand. The layer is dried and the process is repeated 6 or 8 times to build a strong ceramic shell. The wax is then melted away with a steam autoclave with excess wax burned out in a furnace, which leaves a hollow ceramic mold. Molten metal is then poured into the mold and the casted part is broken out after cooling through a knockout operation. The gating and runners are removed through post machine processes and go through final tests and inspections such as non-destructive tests [12,13].

Due to the cost of tool and die for traditional wax patterns, our patterns had to be FDM printed instead. The filament we used was by a company called PolyMaker, and it was a filament called PolyCast which is specifically used for creating investment cast patterns. Three patterns were printed on Bambu Labs P1S, P2S, and H2D. Due to size and print ability limitations, we had to print the gates separately and

split the axe head in 2 parts. They were all then superglued and assembled as shown in Fig.7 . Our company would then weld any remaining seams with soldering iron.

After going through standard ceramic shell making processes, molten 4140 Carbon Steel is poured into the shells, producing the casts. Once the axe heads were cooled and removed from the shells shown by Fig. 8, they underwent heat treatment to further strengthen the axe heads. They were first preheated to 1000.0°F for 2 hours before being transferred to a 1650.0°F furnace to be normalized for 1.5 hours and then air cooled. They were then preheated again before being austenitized in a 1550.0°F furnace for 1.5 hours and then oil quenched. Lastly, they were tempered in a 350.0°F furnace for 3 hours and then air cooled. The final hardness of the axe head was 55 HRC as shown in the heat treatment certification shown in Fig. 9. The axe heads after heat treatment are displayed in Fig. 10.

5.2 Handle Production

The handle stencil was 3D-printed on a Bambu Lab A1 Mini. Given our list of eligible hardwoods, maple was chosen since it was a top contender that was readily available from a local lumber yard and within budgetary constraints. We graded our lot of 12 sample blanks for grain structure, densities, and imperfections, and selected the top pieces to be reserved for our final competition handle. We began utilizing the stencil to trace out the wood handle shape on our lower graded woods and used a bandsaw to cut them out. We used traditional wood working tools to shape the handle and sanded it to smooth the surface. After testing out these handles and deciding that we are satisfied with the results, we began running the same processes on the higher graded woods that we planned on using for the final competition axe. Once the handles were shaped and sanded, they were stained using an off the shelf stain. Once stained, boiled linseed oil was applied as an additional protective layer for the wood.

6. Processing Phase

6.1 Initial Post-Processing

We were able to discuss with our foundry and provide them with a guideline to cut off the gates as well as grind down a large portion of the machine stock around thin sections such as the blade's bevel and the rear spike before heat treatment. Upon delivery, a rough grind was conducted with an 80 grit wheel on a die grinder for the top, bottom, and back sides, and a 60 grit belt on a band file on the flat surfaces. Next, the blade was sharpened with the 60 grit band file until both beveled surfaces properly intersected to create the blade geometry. After the post-hardened rough grind, the axe head was sand blasted with 80 grit aluminum oxide to clean the surfaces of any surface rust or other oxidation. Care was taken throughout the grinding process as to not allow the temperature of any part to avoid reaching the tempered martensite embrittlement range [14].

6.2 Cold Bluing

In order to achieve a darkened metal surface on the recessed features of the axe head, cold bluing was chosen. Brownell's Oxpho-Blue® is an off-the-shelf cold bluing solution used by gunsmiths to touch up or entirely restore the black "blued" finish of some firearms. We chose Oxpho-Blue® for its

ease of application, cost effectiveness, and excellent result. Once dry of brake parts cleaner, a two coat application of Brownell's Oxpho-Blue® was applied according to the instructions. Once blued, a layer of motor oil was applied to saturate and protect the blued surfaces.

6.3 Grinding

Next, a 240 grit wheel on a die grinder was used to finish the curved surfaces of the top, bottom, and rear. The bandfile was used once again this time starting at 80 grit up to 240 grit on the flat surfaces of the sides and rear spike to achieve a high quality brushed finish. The blade was also sharpened up to 180 grit before assembly, we had intended to sharpen up to 240 but stopped as to not make it unsafe to easily handle. A carbide burr on a die grinder was used to grind away small pockets to create eye features upon the horse head portion of our design.

6.4 Assembly

Using traditional carving and fitting methods, the handle was carved until firmly seated to the head. Next, the head was removed and a slit was sawn into the tongue of the handle. The axe head was reinstalled and a wooden wedge was driven into the tongue and cut off where it met the tongue. Finally, a metal conical wedge was installed to further secure the wooden wedge and the head to the handle.

6.5 Final Post Process

Once the axe head was properly seated to the handle, a final sharpening was completed working from 240 grit up to 2500 grit on the bandfile. Fine whetstones were used last to achieve maximum sharpness. The final sharpened axe is shown in Fig. 11.


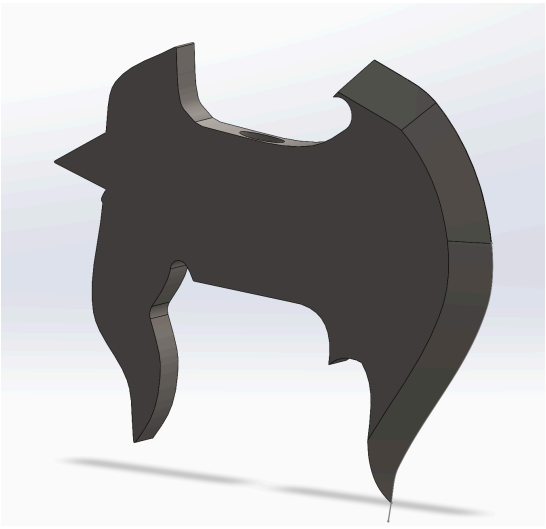

6.6 Testing

Rockwell Hardness C tests were conducted on the axe head by the heat treatment contactor. Yielding a result of a surface hardness of 56 RHC. User testing was conducted on the final axe, both the head and spike were swung against wooden and fruit samples as well thin aluminum and steel plates. The spike was able to pierce both the steel and aluminum samples while the blade only dented them both. Testing was also conducted after leaving the axe in a 15 degree Fahrenheit freezer for 8 hours.

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Appendix

Figures	
Fig. 1: Brainstorm Sketch for Bronco Axe	
Fig. 2: Axe Design #1 CAD Model	
Fig. 3: Axe Design #2 CAD Model	

**Fig. 4: Gating System
CAD Model**

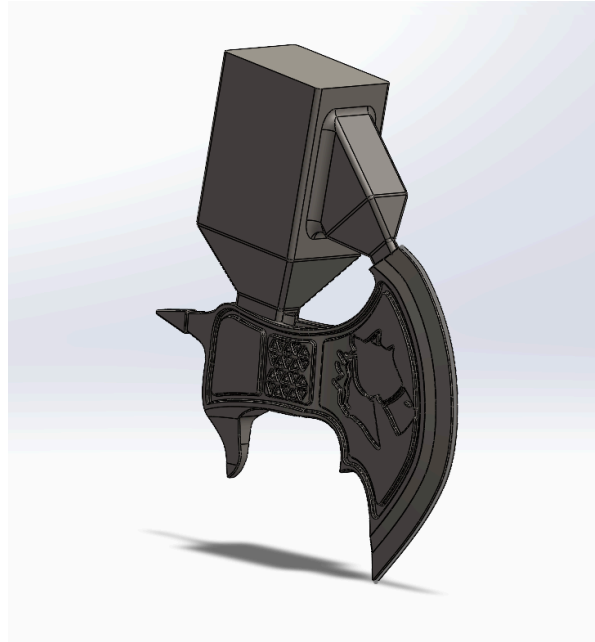
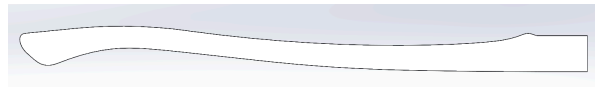


Fig. 5: Handle Modeling



**Fig. 6: Solidification
Simulation**

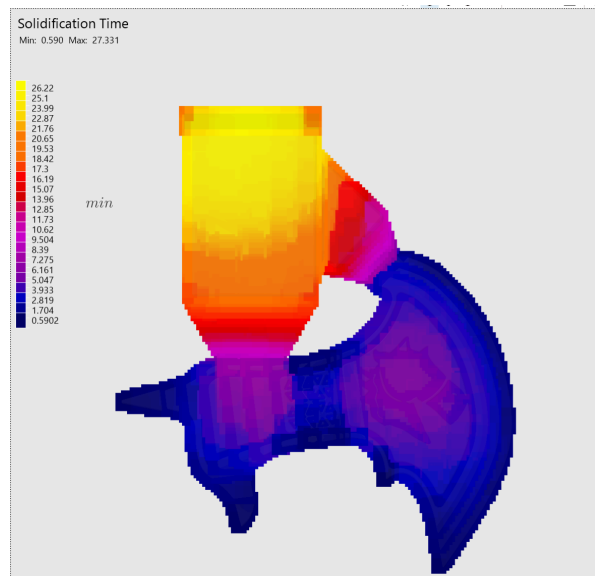


Fig. 7: 3D Printed Patterns



Fig. 8: Axe head post-pour



Fig. 9: Heat Treatment Certification

Quantity	Part Number / Part Name / Part Description	Pounds
2	AXE CAL-POLY HORSEMAN AXE HEAT# 012226, MASTER HEAT# 24-7456	5

Heat Treat

Insp. Type	Scale	Minimum	Maximum	Scale	Minimum	Maximum	Value
Customer Requirements:							
Hardness	HRC	54.0	60.0	HRC	54.0	55.0	
				Results: Hardness 100% hardness inspected (87.4-87.9 HR15N)			

Heat Treated to 54-60 HRC per AMS 5338H and the purchase order.

Furnace	Process	Temperature	Time	Quench Method
CD-15	Preheated	1000.0°F	2 Hour 12 Minutes	Transferred to Furnace
CBM-1	Normalized	1650.0°F	1 Hours 26 Minutes	Atmosphere Cooled
CD-15	Preheated	1000.0°F	2 Hour 9 Minutes	Transferred to Furnace
CBM-1	Austenitized	1550.0°F	1 Hours 21 Minutes	Oil Start 131.9°F/ 139.4°F Max
CD-22	Tempered	350.0°F	3 Hours 6 Minutes	Air Cooled

Fig. 10: Final Axe Head Casts After Pre-Grind and Heat Treatment



Fig. 11: Final Axe



**Fig. 12: Final Axe
Chemical Composition**

Chemical Composition (% by Weight)

Carbon	0.4300	Tungsten	<0.005
Sulfur	0.0240	Aluminum	0.0250
Manganese	0.9400	Boron	0.0001
Chromium	0.9600	Titanium	0.0010
Nickel	0.0700	Niobium	0.0030
Cobalt	XXXX	Tin	0.0090
Iron	BAL	Lead	0.0010
Copper	0.1600	Zirconium	XXXX
Molybdenum	0.1600	Tantalum	XXXX
Phosphorus	0.0100	Oxygen	XXXX
Silicon	0.2700	Nitrogen	0.0080
Vanadium	0.0050	Others:	Se <0.005

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