SFSA Cast in Steel 2025 - George Washington’s Sword
Technical Report

Grand Valley State University - The Great Lake Tea Tossers

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Acknowledgements:

The Casting Club would like to thank all of the key individuals and groups whose contributions made our team successful. First, we would like to thank Mr. Jason Klein, Mr. Jason Bergman, Mr. Josh Gerrans, and Mr. Nic Tarzel from Eagle Alloy, along with Eagle Alloy Inc. for their work in developing our sword. We thank Louis Harrison for lending expertise and resources. We would also like to thank our faculty advisor, Dr. Abishek Balsamy-Kamaraj. We would also like to thank the School of Engineering at Grand Valley State University for its facilities and financial support.

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Executive Summary

The GVSU team, The Great Lakes Tea Tossers, created a replica of the Silver Lion-Headed Cuttoe sword carried by George Washington. The primary manufacturing method for creating the blade was casting and was cast in AISI 8630 steel. Other materials used in the components of the sword include brass and bone. A significant amount of post-process was utilized in the components of the sword such as heat treatment, milling, grinding, polishing, pneumatic chiseling, sanding, and sharpening. The resulting sword measured 36.125 inches overall with a 29.875 inch long blade and weighed in at 2.38 lbs.

1. Introduction

The 2025 Cast in Steel competition objective was to design and create either a replica of one of George Washington's swords or an original sword in a style appropriate for Washington. The Steel Founder's 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. The sword design this year includes design specifications and restrictions on the sword. The overall sword should not exceed 4.4 lbs (2 kg) and should not be longer than 43 in (1.09 m). The sword should be either a single-edged replica that matches the original sword within a tolerance of 2 in or an original sword that is 25 to 43 in long overall with a blade length of 20 to 35 in.

George Washington is known to have used nine different swords throughout his life, some of which were actively used in battle and some of which were mostly decorative. These 18th-century swords include the 1753 Silver-Hilted Smallsword, the Model 1767 French Officer's Epée, the Alte Presentation Broadsword, and the Silver Lion-Headed Cuttoe, among others. The GVSU team chose to replicate the Silver Lion-Headed Cuttoe, which is currently housed at Mount Vernon.

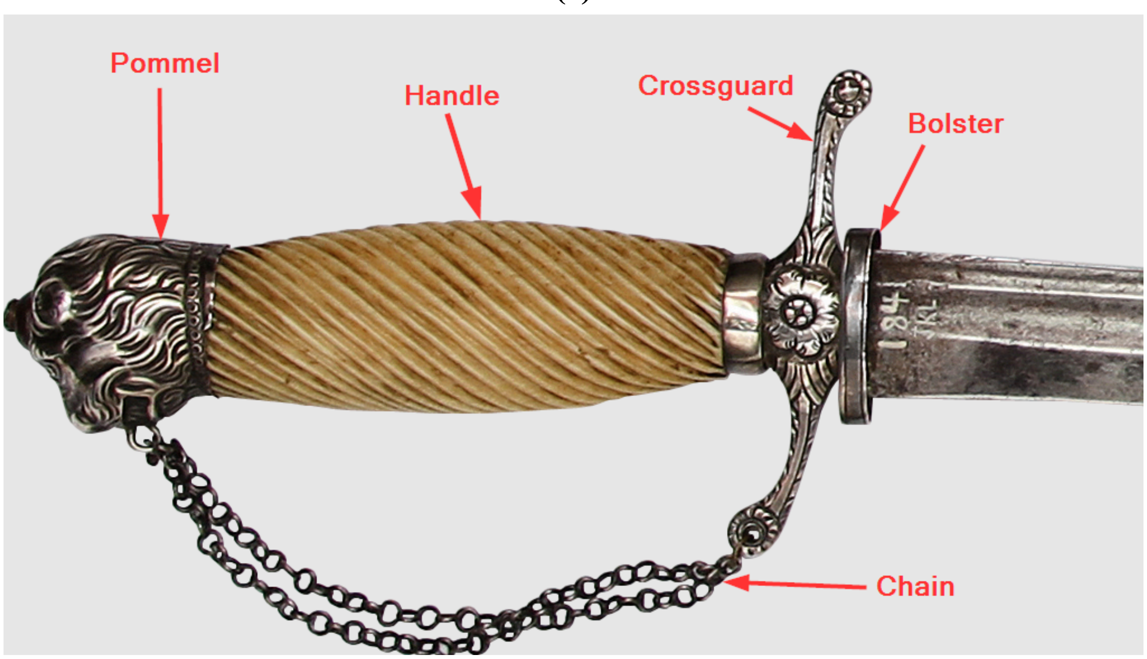
2. History

When it comes to the history of the Silver Lion Headed Cuttoe, little is known. One of the few facts that is known is how George Washington acquired his signature blade. It is said that "Washington acquired the sword in 1770 from Jacob Gooding, who likely acquired it somewhere in Philadelphia"[1]. One of the last well-known places that the blade moved to was his nephew's during his farewell address. He wrote, "These swords are accompanied with an injunction not to unsheath them for the purpose of shedding blood, except it be for self-defense or in defense of their country and its rights; and in the latter case, to keep them unsheathed and prefer falling with them in their hands, to the relinquishment thereof" [2]. Beyond that, very little is known about the whereabouts of his sword, as it is one of the few swords still in private collectors' hands today. The sword can be seen in numerous historical paintings dating back to the crossing of the Delaware, and the beginning of the Revolutionary War. While the whereabouts of it are unknown, numerous photos show the intricacy and careful design that went into one of Washington's most prized possessions.

2.1. Silver Lion-Headed Cuttoe

The Silver Lion-Headed Cuttoe has a distinct design incorporation, unlike Washington's other swords. The pommel of the sword is shaped like a lion's head, which however was a common design for cuttoe swords in Britain in the 1760s [1]. This cuttoe in particular features a blade that is longer than normal as well, at 30 inches. A longer blade would have made sense for a person of a taller stature such as Washington [1]. The sword also contains a handle made from bone which was considered lower status than ivory at the time, and has a cross-guard that is curved slightly around where the knuckle of the wielder's hand would be. And lastly, contains a chain that would wrap over the wielder's hand as well.

(a)



(b)

Figure 1: (a) George Washington's Silver Lion-Headed Cuttoe and Scabbard. (b) Closeup of the hilt assembly with labeled parts.

3. Metallurgical Considerations

The metallurgical considerations for the sword are important because the material choice can dictate behavior and strength. Critical material properties for the design of a sword include the yield strength, the ultimate tensile strength, the modulus of elasticity, and the hardness of the material. The yield strength of a material is used to help define the stress that an object can withstand before it begins yielding or permanently deforming. Stress applied up until this point is elastic and able to let the piece return to its original form after the stress is removed. If the stress applied exceeds the yield strength, the object enters the plastic region of a stress-strain curve similar to Figure 2, and will not return to its original position. The sword's stress needs to stay below the yield strength of the material to make sure that it is durable and will not permanently bend when under stress.

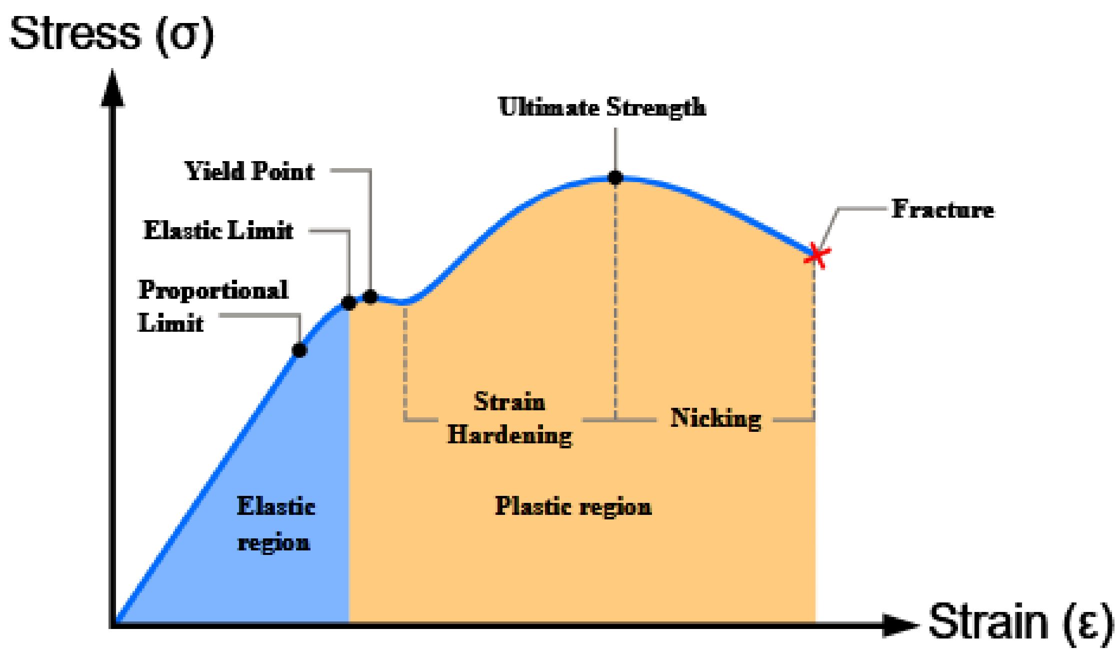


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Figure 2. Stress-strain curve of a material [3].

The ultimate tensile strength is important due to critical failure. The ultimate strength of a material is what determines the point of unstable stress in a part. When a part reaches its ultimate strength, it will typically experience necking if the material is ductile. Necking is a localized area of extreme plastic deformation, typically resulting in an unstable and shrinking cross-sectional area. This will continue if the stress is not removed until a fracture occurs. This is important for the sword because critical failure is unwanted during the testing of the sword.

The modulus of elasticity is an important factor for the sword because it defines the material's resistance to elastic deformation. The more the sword will be able to withstand bending under non-critical stress, the better because it will be more usable and predictable and will be able to experience a fair hit or fair amount of stress before elastically bending.

Hardness is an important material factor because hardness will affect the blade's edge and how well it will hold up after striking something, and how well it will maintain sharpness after repeated cuts. Hardness is a material property that needs to be balanced with the ductility of the material because a very hard material will likely be brittle, which will result in a small elastic region of the material to work within. A material that is not hard enough for a sword or sharp edge, however, will experience edge rolling and not be able to withstand a large number of cuts before the material becomes dull.

3.1 Material Selection

The material used for George Washington's sword was AISI 8630 steel. This steel has a lower carbon content and higher amounts of molybdenum and chromium, resulting in wear and corrosion resistance properties. This material selection also has a fair amount of hardenability, which is essential for making a strong blade edge. The critical material properties for AISI 8630 are found in Table 1. The chemical composition of AISI is found in Table 2.

Table 1: AISI 8630 Material Properties [4]

Properties	Measurement
Ultimate Tensile Strength	620 MPa
Tensile Yield Strength	550 MPa
Modulus of Elasticity	190-210 GPa
Hardness, Rockwell C	15

Table 2: AISI 8630 Chemical Composition [4]

	Fe	C	Mn	Si	Ni	Cr	Mo	Al	P	S
Range	96.745-98.02	0.35	0.95-0.60	0.60-0.30	0.80-0.40	0.80-0.40	0.25-0.15	0.90-0.30	0.04 max	0.45 max

A spectrometer was used to verify the chemical composition of the metal that the sword was made from. A small sample was taken just before the actual mold pours to achieve this. Figure 3 is a picture of the spectrometer used. Figure 4 shows the results from the spectrometer reading.

Figure 3: Spectrometer used.

	B	C	Al	Si	P	S	Ca	Ti	V
	%	%	%	%	%	%	%	%	%
Run 1	0.0007	0.3160	0.0512	0.5234	0.0170	0.0238	0.0007	0.0259	0.0076
Run 2	0.0008	0.2938	0.0579	0.5251	0.0175	0.0525	0.0007	0.0140	0.0076
Average	0.0008	0.3049	0.0545	0.5243	0.0173	0.0382	0.0007	0.0200	0.0076
RSD%	11.21	5.15	8.77	0.24	1.96	53.33	5.62	42.13	0.11

	Cr	Mn	Co	Ni	Cu	Zn	As	Nb	Mo
	%	%	%	%	%	%	%	%	%
Run 1	0.9646	0.8587	0.0069	0.8017	0.0683	0.0032	0.0024	0.0099	0.2105
Run 2	0.9492	0.8225	0.0071	0.8043	0.0724	0.0029	0.0026	0.0095	0.2091
Average	0.9569	0.8406	0.0070	0.8030	0.0704	0.0031	0.0025	0.0097	0.2098
RSD%	1.14	3.04	2.00	0.23	4.10	8.78	5.81	3.06	0.49

	Sn	Sb	W	Pb	Bi	CE_Calc.	CE_Calc. +	Fe%	Fe4
	%	%	%	%	%	%	%	%	kcount
Run 1	0.0038	0.0019	0.0018	0.0063	0.0047	0.7536	0.8409	96.0889	26.2100
Run 2	0.0039	0.0046	0.0024	0.0059	0.0049	0.7225	0.8100	96.1287	27.0210
Average	0.0039	0.0032	0.0021	0.0061	0.0048	0.7381	0.8254	96.1088	26.6155
RSD%	2.08	58.56	19.75	4.30	3.01	2.99	2.64	0.03	2.15

	Fe4N	HARDENAE	RESIDUAL
	kcount	%	%
Run 1	222.3830	154.2649	2.0528
Run 2	225.1790	137.5049	2.0426
Average	223.7810	145.8849	2.0477
RSD%	0.88	8.12	0.35

Figure 4: Spectrometer chemistry results.

The aluminum in the spectrometer results is lower than expected due to it being added later as a deoxidizer. The other elements of the composition all meet their goals according to the spectrometer.

The Silver Lion-Headed Cuttoe features more components than just the blade and tang. It also has a crossguard, handle, and pommel that are part of the hilt assembly. The crossguard was CNC machined out of steel because of the intricate shape and engravings that were wanted on it.

The pommel was cast out of bronze as a cylindrical slug and engraved by hand using a pneumatic chiseling tool to make the head resemble the lion's head. Lastly, to stay original to the sword, the handle was shaped from bone to be as authentic as possible and to provide a less slippery grip than metal or wood.

4. CAD Model

The computer-aided design (CAD) model of the sword was done with Solidworks and as an iterative process. The beginning drafts of the sword CAD were rough models of the shape of the design with minimal details and depth. The design of the sword was made as closely as possible to the real sword as the designing process continued. The initial design is shown in Figure 5. The design was made in SolidWorks, and done primarily by importing an image of the Silver Lion Headed Cuttoe and tracing the profile of the sword. Thickness was added to the blade and set to a thickness of 0.3 inches. The transition from the hilt to the blade was also modeled in the initial design of the sword.

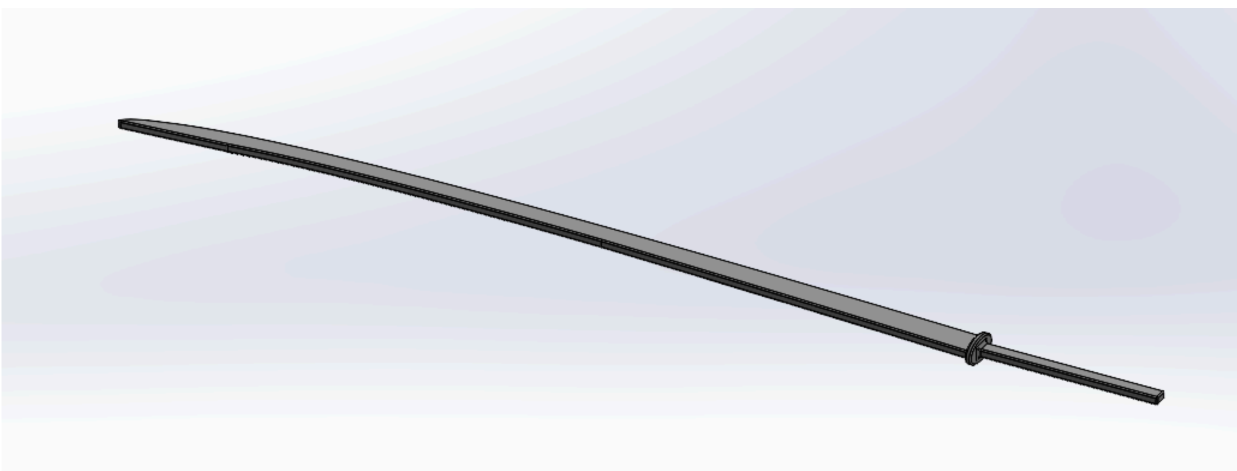


Figure 5: Initial CAD design of the sword.

Because the design of the sword was a replica of the cuttoe selected, the design did not need any further customization from the team. This design also satisfied the design criteria for the sword such as the minimum and maximum length requirements for the sword and blade.

5. Design Alterations for Castability

To make the sword castable, some design changes needed to be made to make the cast successful. When casting one of the primary concerns is the thickness of the part. Thin sections will cool very quickly and risk not filling out completely. Thus, the geometry needed to be changed mildly to accommodate the thin profile of the sword. The first change made to the design of the product included adding more thickness to the blade and tang. Another change added to the mold included adding large fillets at the sharp corners throughout the sword to increase the chance of a successful cast.

To complete the mold as a mold pattern, the sprue was added to the face of the blade to have a place to pour into the mold. In addition, the model was also altered to include a large block through the middle of the sword and countersunk bolt holes along the length of the blade. The large block was added to the pattern to provide an easy method of locating the pattern in the flask. The flask included a large recessed hole in the bottom face that the pattern could be easily inserted into. Figure 6 shows a closeup of the sprue on the model of the sword pattern. Figure 7 shows the large block that was added to the sword.

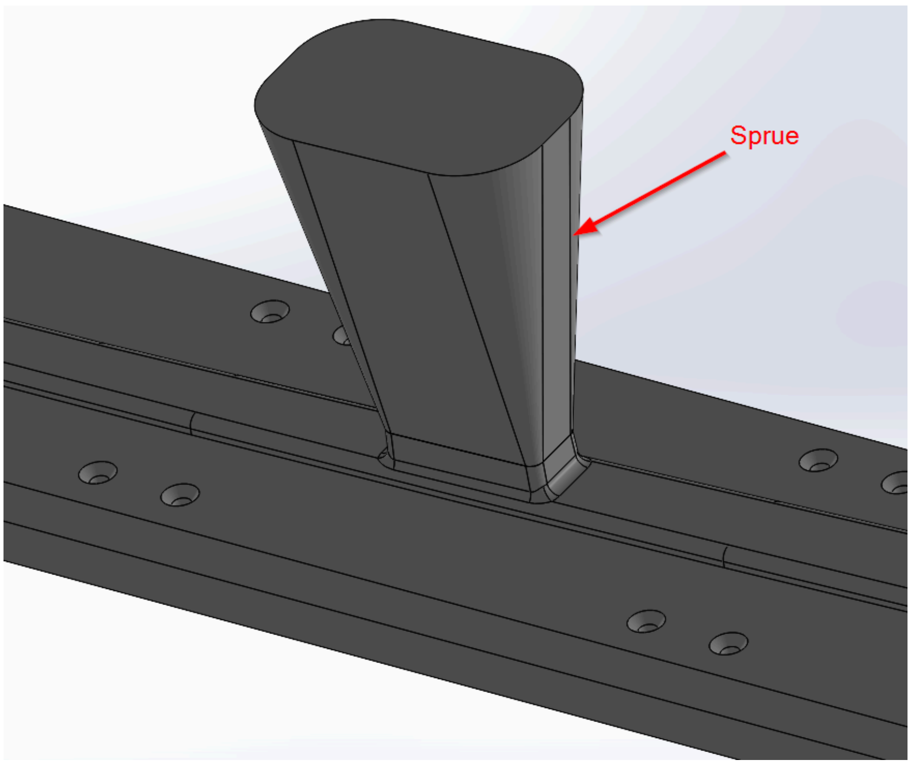


Figure 6: Pattern sprue.

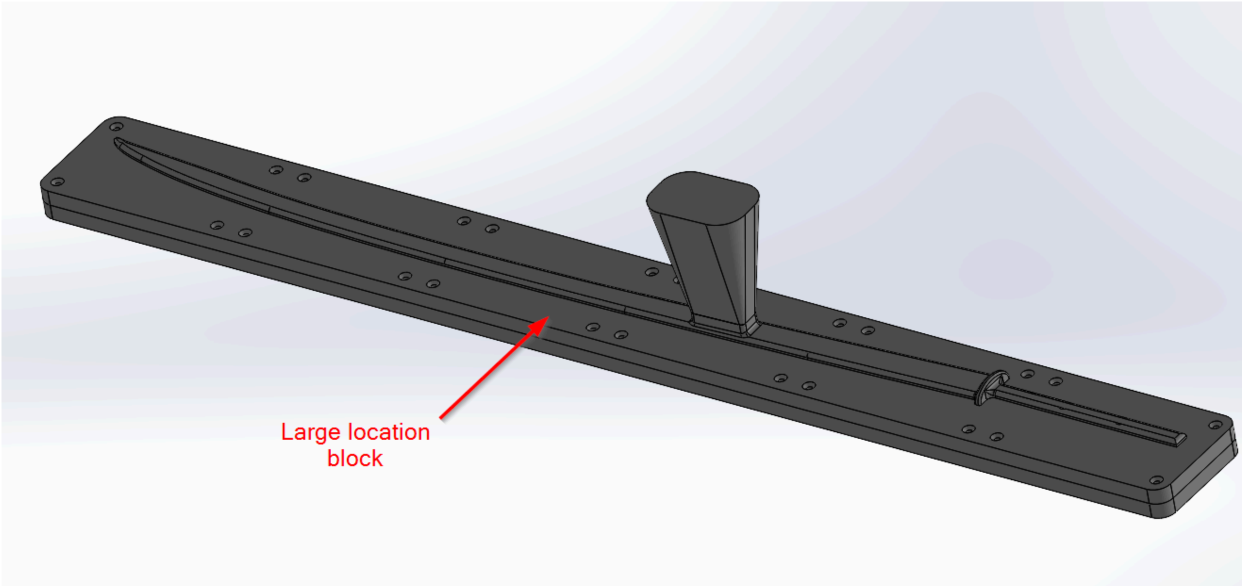
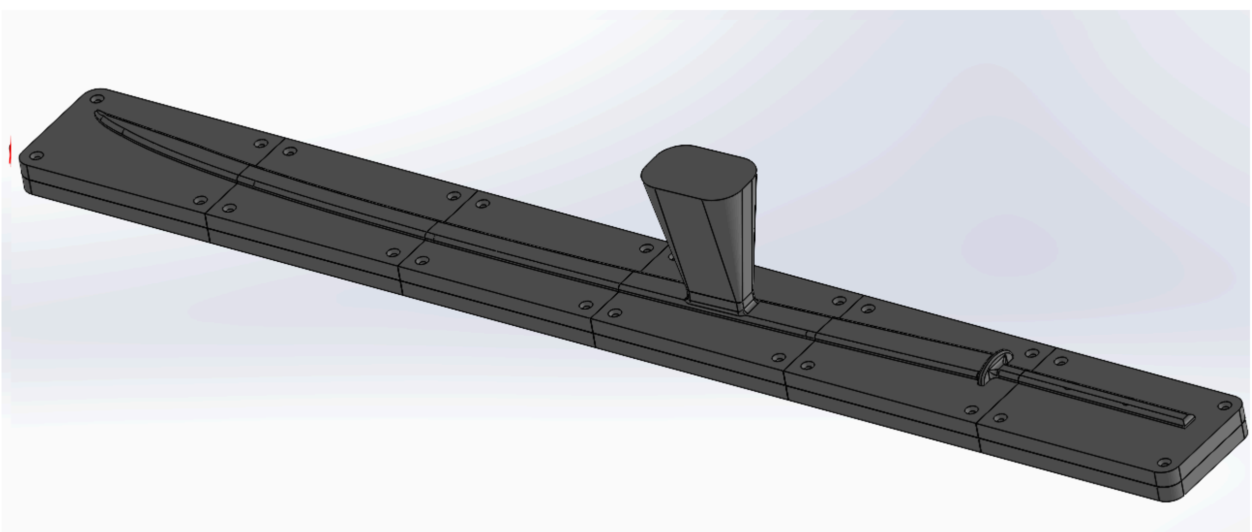
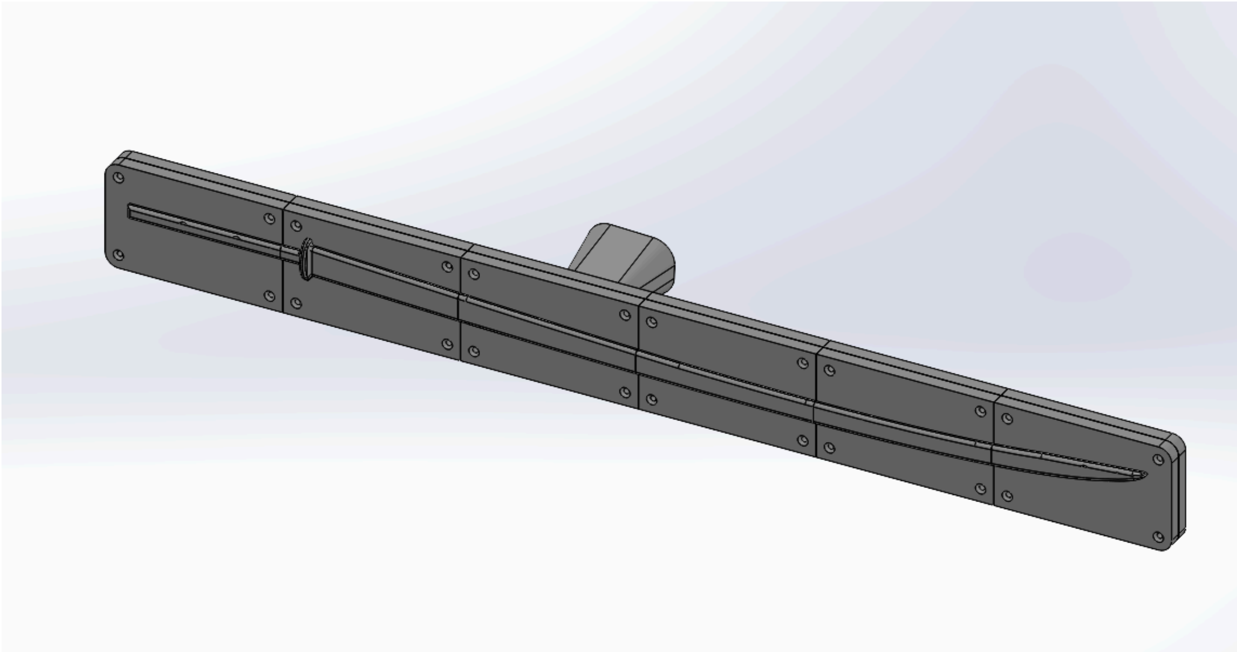


Figure 7: Pattern location block.

The last step in the casting design was sectioning the pattern to make it 3D printable on material extrusion printers. The model was split horizontally for the cope and drag sides of the mold and then it was also split into 6 sections along the length of the sword to fit into pieces on a 3D printer. In addition, the sprue was also made as a section by itself. Figures 8a and 8b show the model sectioned up. In total, the pattern used 13 different sections. All of these were printed, placed, and fastened into the cope (Figure 9) and drag (Figure 10) flasks.



(a)



(b)

Figure 8: Cope (a) and drag (b) sides of the combined and sectioned pattern model.

Figure 9: 3D printed pattern pieces placed and fastened in the cope flask.

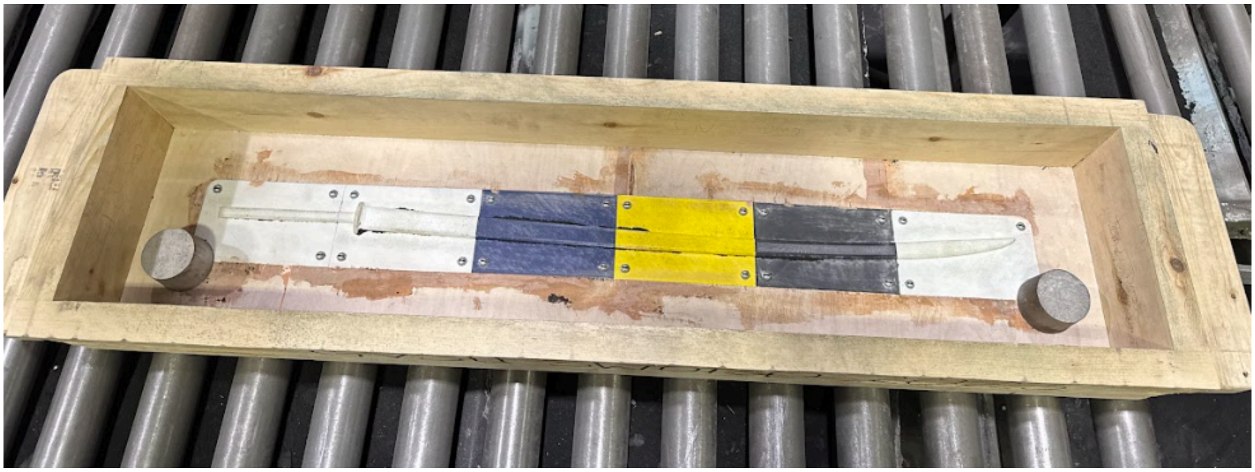


Figure 10: 3D printed pattern pieces placed and fastened in the drag flask

6. MAGMA Simulations

MAGMA is a simulation software that evaluates the properties of the cast based on the selected gating system. From the simulation, the best gating could be determined. To find the best location, a hot spot, temperature, and porosity simulation were conducted. Figure 11 contains a screenshot of the microporosity simulation of the mold. Figure 12 shows the hot spot simulation results.

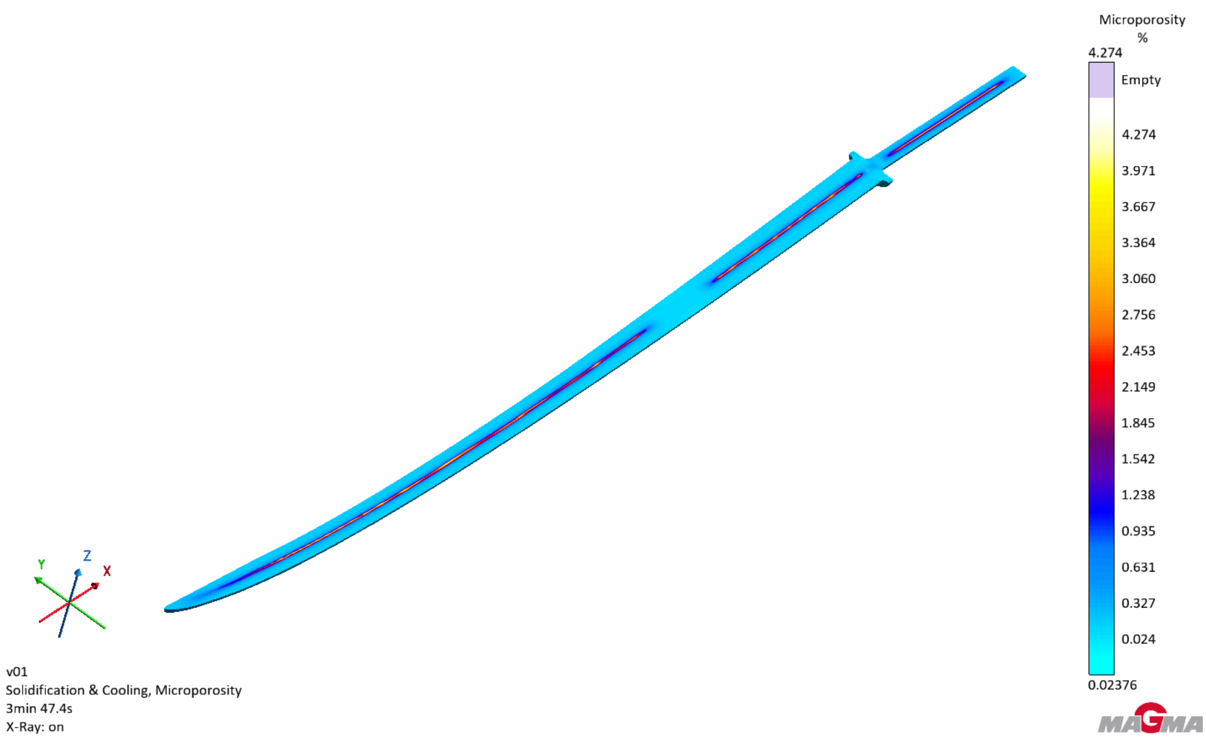


Figure 11: MAGMA microporosity simulation results.

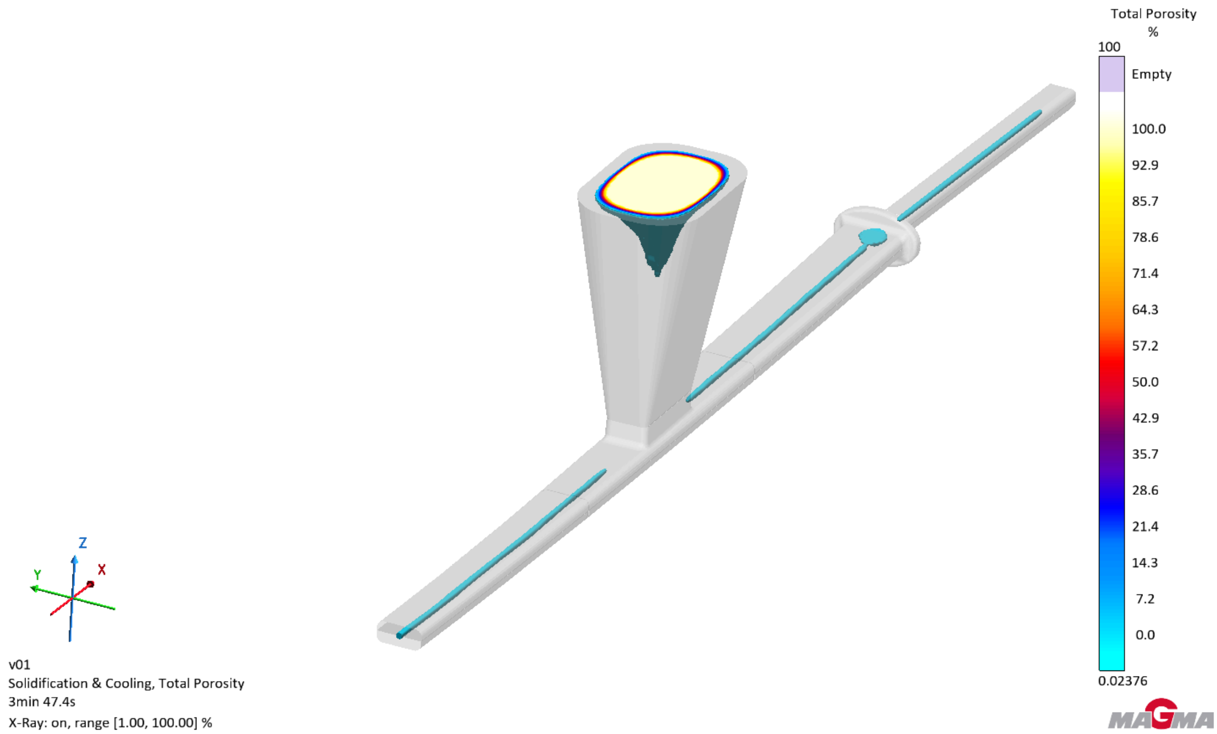


Figure 12: MAGMA hot spot simulation results.

From the simulation, the blade displayed a minor amount of porosity with most of it localized to the center of the blade, indicating centerline shrinkage. This is expected in a long, thin, slender part. Besides that, little porosity was predicted elsewhere in the blade. The hotspots in the blades were also localized around the center of the blade. The team was confident that the blade did not require risers to reduce the porosity in the blade.

Later on, x-ray images of the cast swords were used to validate the simulation results. Overall, the porosity shown in the blades was minor and did not significantly affect the blades post-processing. The sword that was chosen as the competition sword was determined by the x-ray photos, showing that both blade #3 and #1 provided the least porosity of the 4 blades. Blade #4 produced significantly higher porosity than the other blades, as shown in the x-ray photos, Figures 13, and 14. The team decided to go with blade #3 as it exhibited the lowest overall porosity.

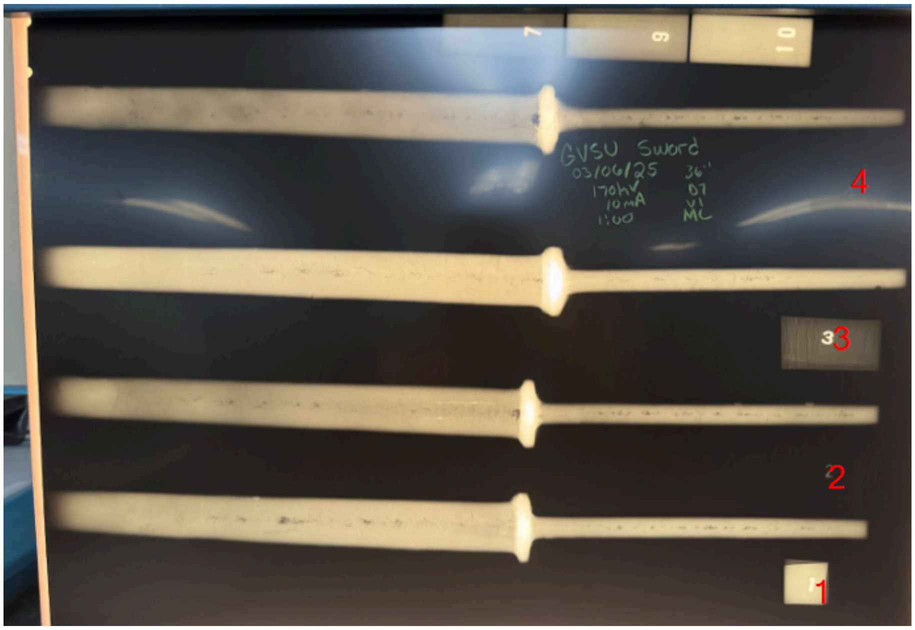


Figure 13: X-ray image of sword handles.

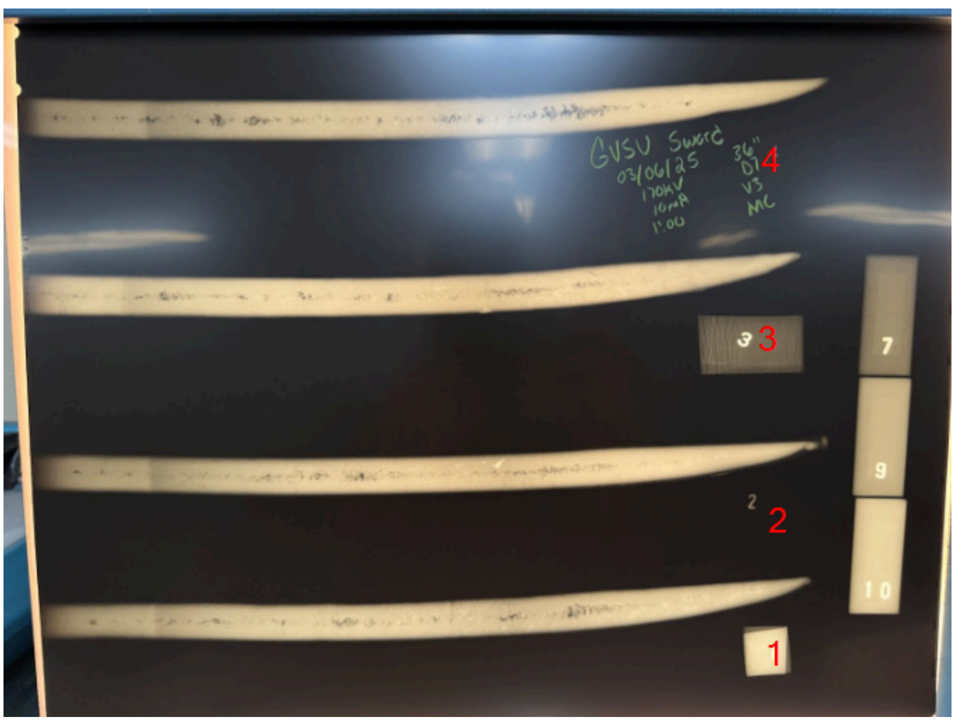


Figure 14: X-ray images of sword ends.

7. Casting Process

The CAD model was 3D printed and screwed to the bottom of a mold, as seen in Figure 15. The sword's cope and drag pattern were assembled. The molds were filled with airset sand and vibrated to get all of the airset to settle in the mold. Figure 16 shows the airset being poured into the mold. Once settled, the molds were left to harden from the binder. The two sides of the mold are in Figures 17 and 18.

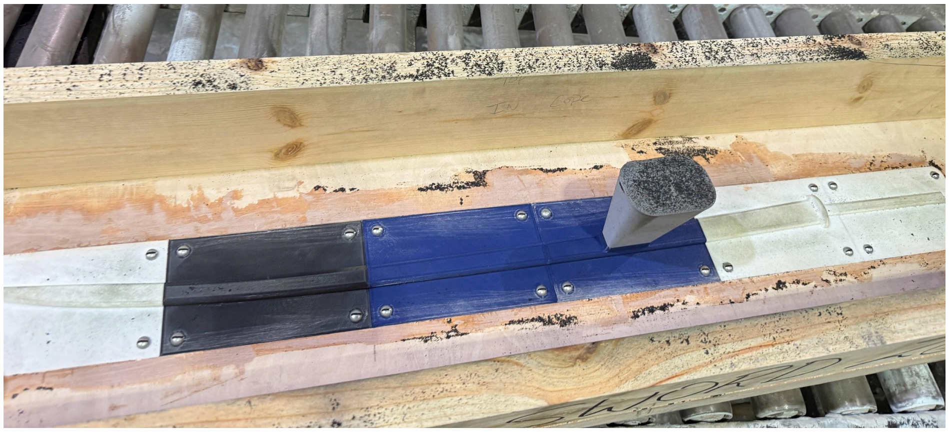


Figure 15: Mold before being filled with airset sand.

Figure 16: Airset sand being poured into the mold.

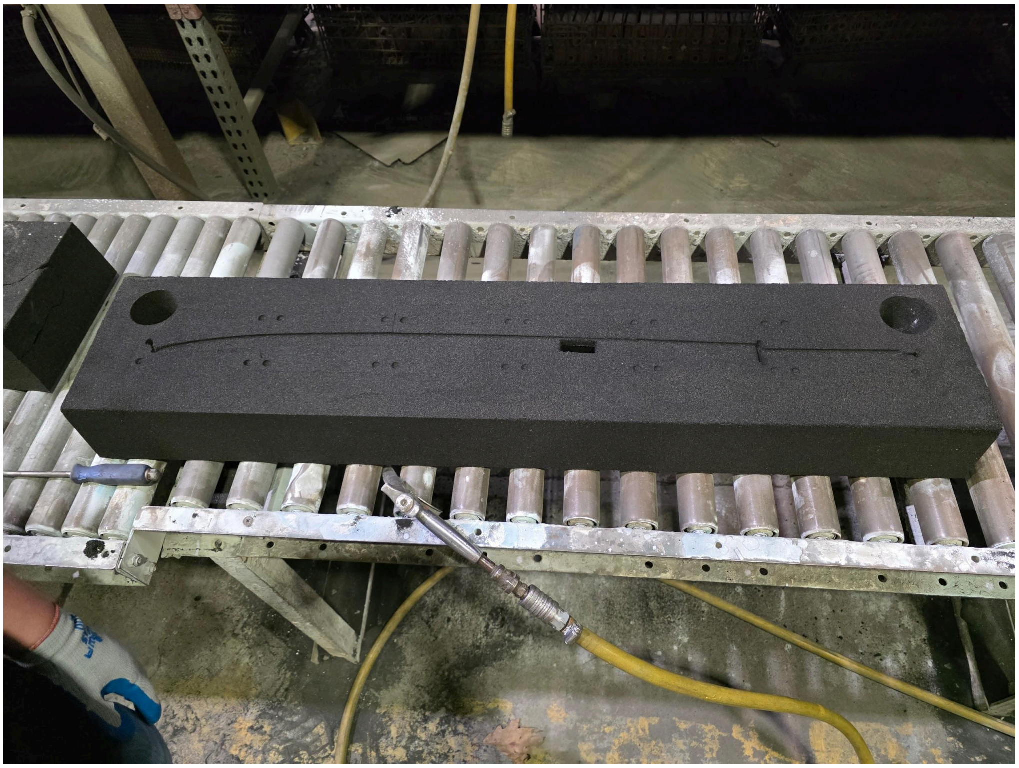


Figure 17: Finished and released cope mold.

Figure 18: Finished and released drag mold.

Scoring of the mold was done in a few locations (one of which was the guard area), so the air could escape when the steel was being poured. Pressurized air was sprayed across both mold surfaces to clear debris from them. The scoring marks are shown in the Figure 19.

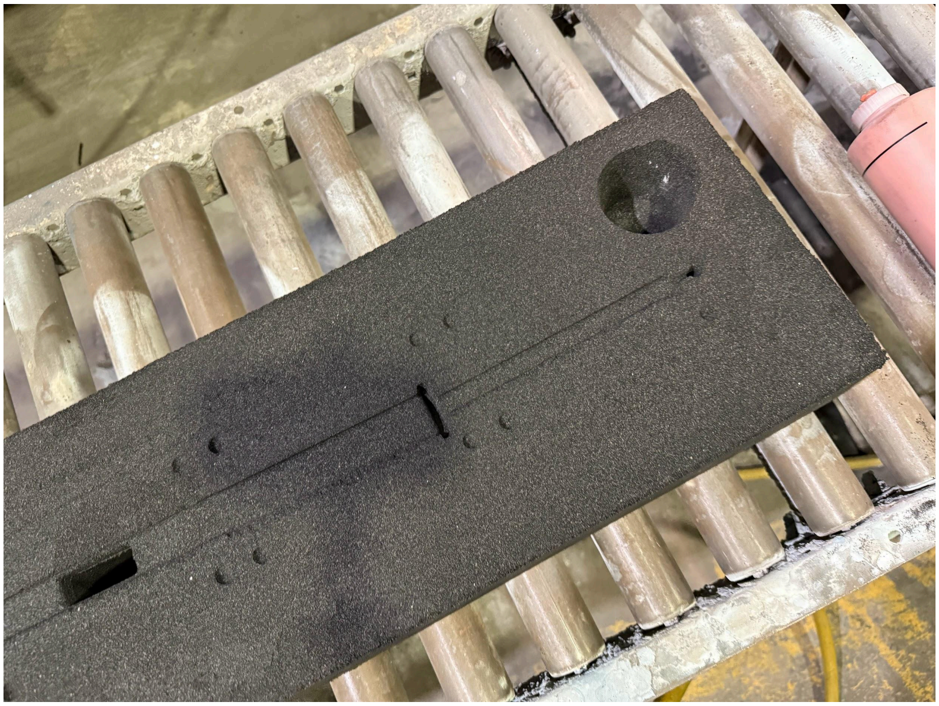


Figure 19: Blade region scoring.

The molds crumbled slightly at their corners. To fix this, an adhesive was applied to the broken chunks of the mold. These chunks were then reapplied to their respective molds, shown in Figure 20. The same adhesive was applied to the faces of both sides of the mold to glue them together, as shown in Figure 21.

Figure 20: Affixed broken mold pieces.

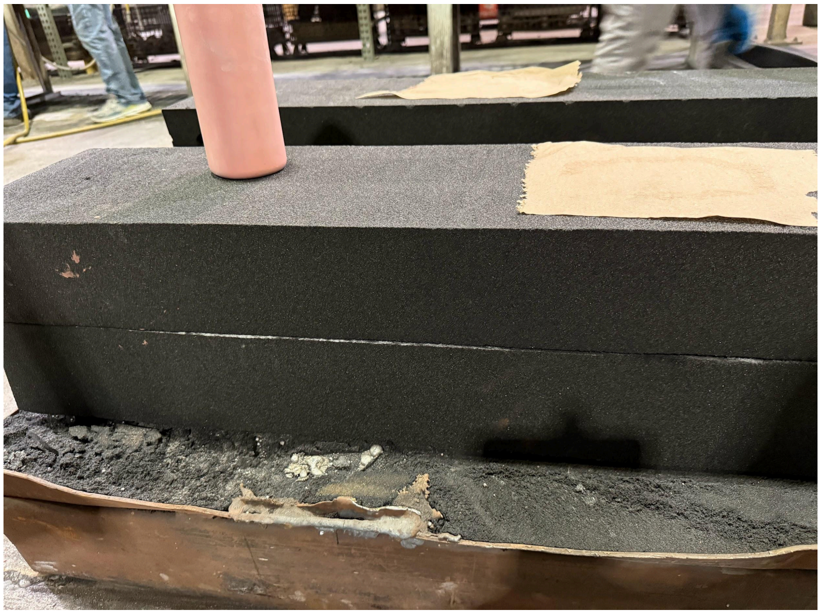
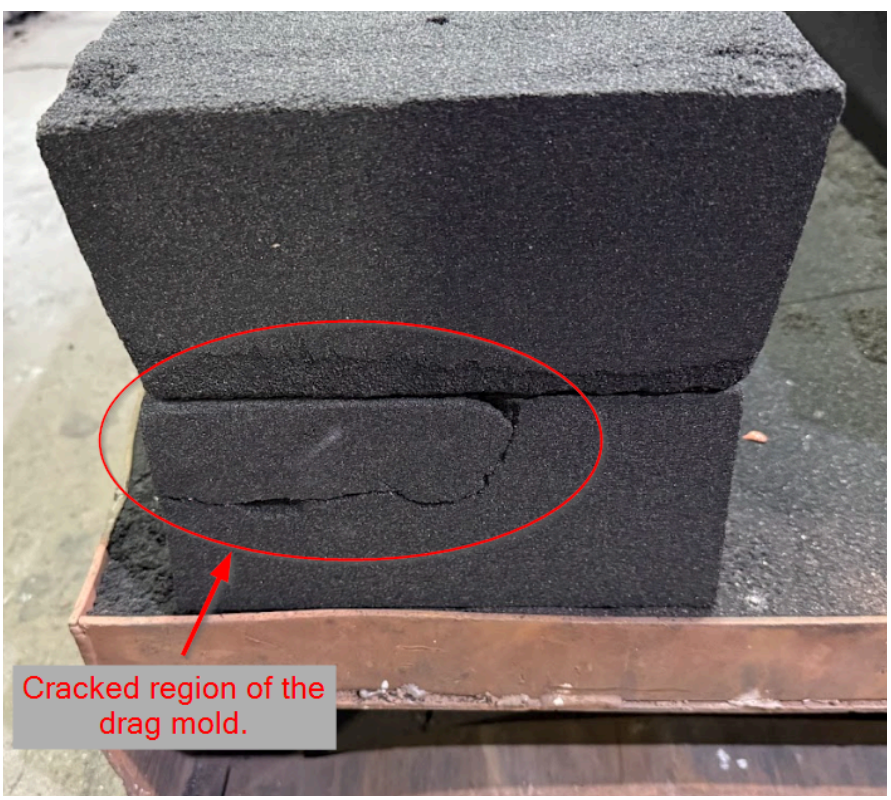


Figure 21: Cope and drag assembly

Airset sand was then hand-applied to the mold to fill any final gaps. Figures 22a and 22b show a before and after of filler airset sand being applied to the divide between the cope and drag sides of the mold, and to the cracked areas of the mold.



(a)

(b)

Figure 22: (a) before and (b) after hand applying airset to the mold halves.

After the top and bottom of the molds were connected, the entry hole for the molten metal needed a funnel to properly fill the unit. Finally, a paper tower was glued over the top to prevent dust from getting into the mold. The final assembly of the mold can be seen in Figure 23.

Figure 23: Fully prepared molds.

Carbon was added to reach an AISI 8630 steel within the crucible. Each of the swords was poured at 3000°F from a ladle.

Figure 23: Metal being cast into the molds.

8. Post Processing

8.1 Getting to Size

Post-processing of the sword was done to get the blade thickness down on both sides of the sword as well as to improve its look, quality, and performance. The cast sword had a thickness of 0.396 inches. This thickness was brought down to 0.25 inches using a manual mill and a face cutter bit equally on each side of the blade. The tip and base were left unmilled as these were the spots that were clamped. Later, these areas were hand-grinded down using grinding wheels and flap discs. A belt sander was used to further shape the blade and get it down to size.

8.2 Heat Treatment

A heat treatment was done on the sword to increase the hardness of the blade's edge. The blade's edge needs to be hard to be able to maintain a sharp edge after continuous use. When a material is hardened it becomes more resistant to denting, however, a drawback of a hard material is that it tends to become brittle. A very hard material, when subjected to a large amount of stress, can experience catastrophic failure and cracking. The opposite of a brittle material is a ductile material which is useful for durability, and thin parts can provide a significant amount of flexibility and toughness but will dull more quickly. A balance of hardness and toughness is essential for the functionality of the blade.

The heat treatment was only performed on the blade of the sword and not the tang. The tang was left unhardened for greater durability and to refrain from introducing internal stresses in the transition piece from the tang to the blade as this was a stress riser point. The blade was heated up to the austenization temperature of 1600ºF [5] and quenched in oil.

To get a base hardness of the material a small sample from a test bar poured from the same batch of material was taken, polished, and tested with a hardness testing machine. The test bar can be seen in Figure 24. To get a post-heat treatment hardness test, a sample taken from the and put through the same heat treatment as the blade. And similar steps were taken to get the

Samples taken for the hardness testing were done by taking three separate points of hardness to see how the hardness changes moving from the center of the bar to the outer surface of the bar. An example image can be seen in Figure 25. The steps were repeated for both an unhardened and hardened test piece. The results of the tests can be found in Table 3, where R is equal to the radius of the test piece.

Figure 24:. Test bar sample.

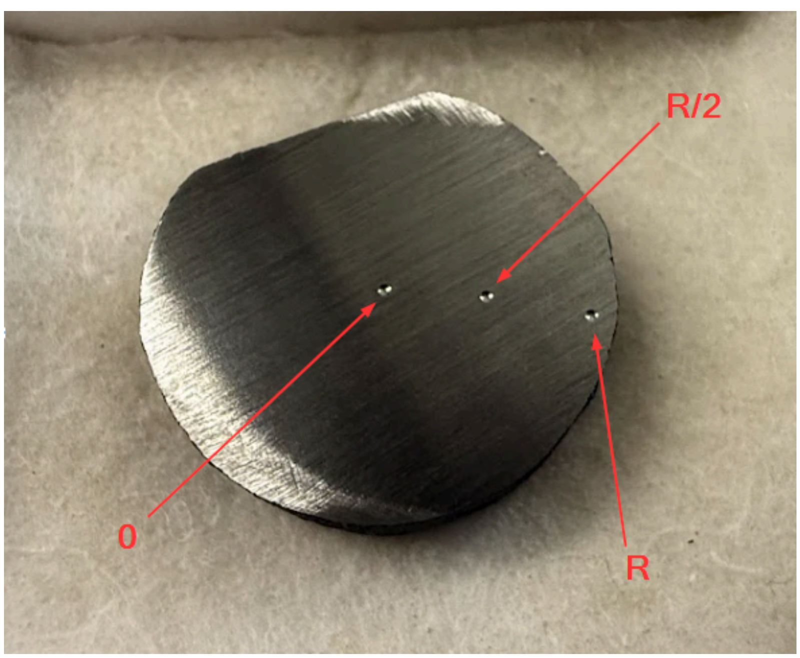


Figure 25: Example of hardness data collection for test bar.

Table 3: Hardness Values of Unhardened and Hardened Samples

	Unhardened Sample	Hardened Sample
Location (x)	Hardness (HRC)	Hardness (HRC)
R	25	41
R/2	25	41
0	24	40

The results from Table 3 indicate that the unhardened sample has a very similar hardness of material throughout the thickness of the part. The hardened sample is as well however significantly harder than the unhardened sample. This indicates that the hardness of the blade should be higher than before and should be able to hold a sharp edge better than if it were not hardened. The small variability in hardness from the center of the sample to the edge is allowable as well and mostly ideal. A slightly softer core of the sword should increase the durability of the sword. Additionally, the hardness that was achieved is similar to what is expected from other studies. A hardness of 41 HRC was achieved while, for this material, 39 HRC is usually expected [6].

8.3 Polishing and Sharpening

The process of polishing and sharpening the sword happens in progressively finer steps. Originally, the cast sword was bulky, thick, and had a lot of additional material. An “as cast” object is traditionally has a lot of scale and the blade of the sword has no sharp edge. To amend this, a succession of finer and finer grits of sandpaper were used to bring the sword down to size, and then make it smooth and shiny.

8.4 Assembly

The sword assembly is made up of five main pieces. These include the blade itself, the crossguard, the handle, the pommel, and a chain. The handle had a hold drilled through it and was then fitted onto the tang up against the crossguard, which similarly, had a hole drilled through it and a large countersink added to the top side to achieve a more flush fit against the bolster. Epoxy was used in all of the crevices between the crossguard and bone and tang to ensure a secure fit. On the bottom of the hilt, a custom pommel was created. The pommel in was made of brass and engraved to resemble the lion head on the pommel of Washington’s sword. The pommel is held in place using epoxy as well

9. Conclusion

The material used in the GVSU team's George Washington sword was AISI 8630 steel and quench hardened. The hardness of the sword was measured to be 41 HRC versus the 25 HRC that it started as. The blade contains authentic characteristics such as the profile of the blade, the material of the handle, and the geometries of the crossguard and pommel.

Challenges of this project include having to design the sword thick enough to make a successful cast, while simultaneously coming up with a plan to machine it down to a usable size for the sword in a reasonable amount of time. A method of making the smaller intricate parts of the sword is also challenging because obtaining finer details is very difficult and can lead to failures in casting. Figures 26 and 27 show the finished sword and a close-up of the finished hilt respectively. The final specifications of the sword can be found in Table 4.

Figure 26: Finished sword.

Figure 27: Close-up of the finished sword hilt.

Table 4: Final Sword Measurements

Specifications	Measurements
Weight (lbs)	2.38
Overall Length (in)	36.125
Blade Length (in)	29.875
Hardness (HRC)	41

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