SFSA Cast In Steel 2025 – George Washington’s Sword Technical Report

Georgia Southern University – Partners in Crime

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1. Introduction

This is the report documenting the creation of the team's rendition of one of George Washington's swords at Georgia Southern University for the 2025 Cast in Steel competition. SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available.

Swords had been a common weapon longer than we have had written history. With swords improving as technology improved to go from bronze to iron to eventually steel. These swords came in many styles depending on the civilization that used them and the technology available at the time. Each sword style was designed for a specific purpose that suited the warfare and combat of the time period. Starting in the 16th century, swords started to become more of a status symbol as well as its use as a weapon. The sword designs and styles continued to change to better suit the combat of the time but, the hand guard, handle, and pommel changed to become more ornamental. The sword could contain specialty materials, gemstones, engravings, or etching to match its user with the more extravagance of the sword displaying its user's status in society or the military. Many of these swords became family heirlooms that were passed down through the generations.

Figure 1. Drawing of an Assyrian Bronze Sword

One sword used as both a status symbol and military weapon in the 18th century was a European hunting sword called a cuttoe or hangar. This sword was a popular choice among officers and infantrymen alike due to its compactness and slashing or stabbing capabilities. The sword has a short, slightly curved one-edged blade made from carbon steel that was typically 24 or 27 inches long. Compared to the 30 or 33-inch swords used during that same time, the cuttoe became a favorite for close-quarters combat. The blade also contained a fuller to reduce the weight of the sword without harming the strength and rigidity of the blade. The cuttoe's handguard protected the user's hand with either a chain or a rigid band connected to the pommel of the sword. Depending on the status of the user, the handguard, handle, and pommel may be of exotic or expensive materials with very decorative animal head pommels being popular.

Figure 2. Image of American Cuttoe

During this time, many in the American colonies became fond of the cuttoe leading blacksmiths and sword makers to begin manufacturing American cuttoes. These American cuttoes used a lot of the same features that European cuttoes did and became the primary sidearm for revolutionary soldiers in the Continental Army. One such person who carried an American cuttoe was General George Washington. Of his seven swords displayed at Mount Vernon, two of them are of the cuttoe variety. His Silver Lion-Headed cuttoe that he carried prior to the Revolutionary war when he served in the Virginia Militia and under the British Empire and his Bailey Silver and Ivory-Hilted Cuttoe he has been depicted as carrying throughout the American Revolution.

Figure 3. Image of George Washington's Silver Lion-Headed Cuttoe

2. Design

2.1 Sword Design

The team chose to create our own original sword based on George Washington's Silver Lion-Headed cuttoe. To create our sword, it was designed in four parts (blade, guard, pommel, and handle) to allow us to use different casting methods to produce the necessary amount of complexity for each part. The blade was designed to be cast with a no-bake sand mold therefore all features were drafted. The sword's shape was formed through replication of the traditional cuttoe curve using image reference with a blade length of thirty inches and an overall length of thirty-seven inches. The blade had a width of one and a quarter inches at the base that tapers closer to the tip of the blade to reach a fine point. The blade has a four-tenths of an inch wide fuller on either side of the blade following the contour of the blunt edge of the blade that will be ground into the casting during finishing. The casting was designed to show how directional solidification can improve sword quality and add value to the sword as compared to a forged sword. The tang was designed to be forged out to 7 inches after casting to decrease the chance of porosity and misruns occurring in that section of the casting. The tang would then be cut and peened to remain hidden.

The guard and pommel were designed with finer details and with the intention of being investment cast. They were modelled with the Silver Lion-Headed cuttoe as a basis. However, the guard and pommel were designed to include eagle depictions in honor of our national bird the Bald Eagle. This choice was made as lions were a popular depiction of the British Empire and the team wanted to make a truly American sword to honor the work that General George Washington performed to found this great nation. The guard and pommel were designed to be made of brass to add symbolism to the birth of our nation by including the material that swords were originally made using to show the young nation he helped build would continue and evolve through the ages. The handguard included our school's logo which the team found fitting with our school mascot being an eagle. The addition of the motto "GATA" and the names of the two members of the team, while not authentic, were added to show the complexity of the geometry investment casting could accomplish.

2.2 Alloy Selection

A proprietary steel that was custom-designed for ground-engaging tools application was selected because of its combination of great hardness, strength, toughness, and work hardenability. Our foundry partner, Carolina Metal Casting, pours this steel for a variety of components. The target composition of the steel is 0.3C-1.1Mn-1.6Si-2.1Cr-0.51Ni-0.32Mo. This metal is typically heat treated at an austenitization temperature of 1688°F followed by agitated oil quench and tempering at 392 °F. The expected properties of this steel after heat treatment are 52 HRC hardness, 252 ksi tensile strength, and 15 ft-lb impact toughness at room temperature. The actual composition and properties were tested in our university's labs and can be found in section 3.8.

2.3 Gating and Riser Design

The gating and risering of the sword was essential to the production of a clean and sound casting. There are several factors that go into designing the gating system such as filling velocity, filling temperature, and porosity. To produce the most sound casting, the gating was designed to reduce the ingate velocity as much as possible (below 28 in/s or 0.7 m/s) while still filling completely and in the shortest amount of time. A uniform, candelabra gating system was chosen to allow for close to uniform filling of the mold with minimal heat loss from the melt to prevent misruns or folds in the casting. Sharp angles were smoothed and ramps were added at the runner and in-gates to reduce mold erosion and turbulence in the gating system and casting. Extensive simulation work was conducted to optimize the gating and riser design to ensure smooth and complete filling watching the velocity at the in-gates and the temperature of the melt during filling. The simulations were run using MAGMAsoft 5.4.

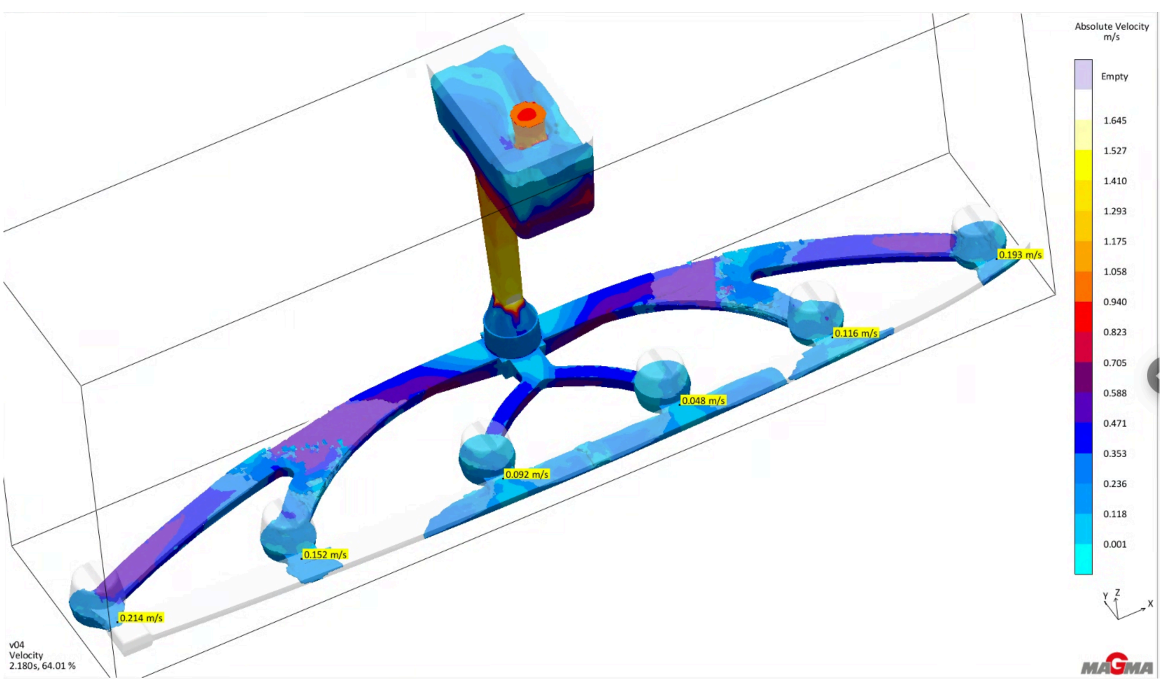

Figure 4. In-gate velocity MAGMA simulation showing non-turbulent flow entering the sword

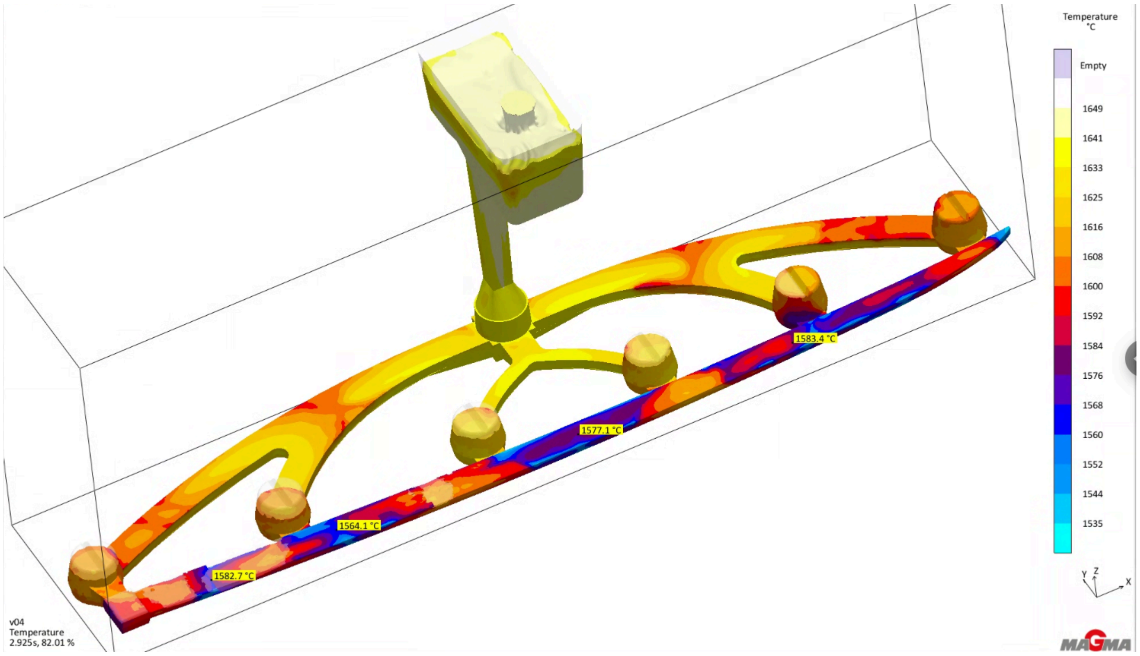

Figure 5. Filling temperature as the melt fronts meet to avoid cold shut

Proper riser size and placement are crucial due to steel being very prone to forming shrinkage porosity. The casting must be adequately fed to minimize the shrinkage porosity in the casting and prevent a catastrophic failure. The first iteration of the riser involved a large continuous riser encompassing the blade of the sword. This continuous riser showed no shrinkage porosity in the rest of the casting with porosity in the center of the continuous riser. This porosity would then be removed through forging and the rest ground off during post-processing. The team decided this design while it would lead to a porosity-free casting would result in excessive post-processing to be done. The team opted for a hot riser design with a similar overall mass to the continuous riser design. Porosity was simulated to be in the centerline of the blade and a small pocket inside the tang section. The porosity in the center of the blade was inevitable with the hot riser change but was minimal and away from the tang and blade joint. This porosity could have been removed through the addition of a chill along the spine but that would affect the directional solidification we were trying to achieve in the blade. The porosity in the tang can be ignored as the tang will be forged to length which will eliminate the porosity. With the final simulation run, the team was confident that the sword would fill properly with minimal porosity in the casting with a fast filling time of three seconds to limit heat loss pouring each mold.

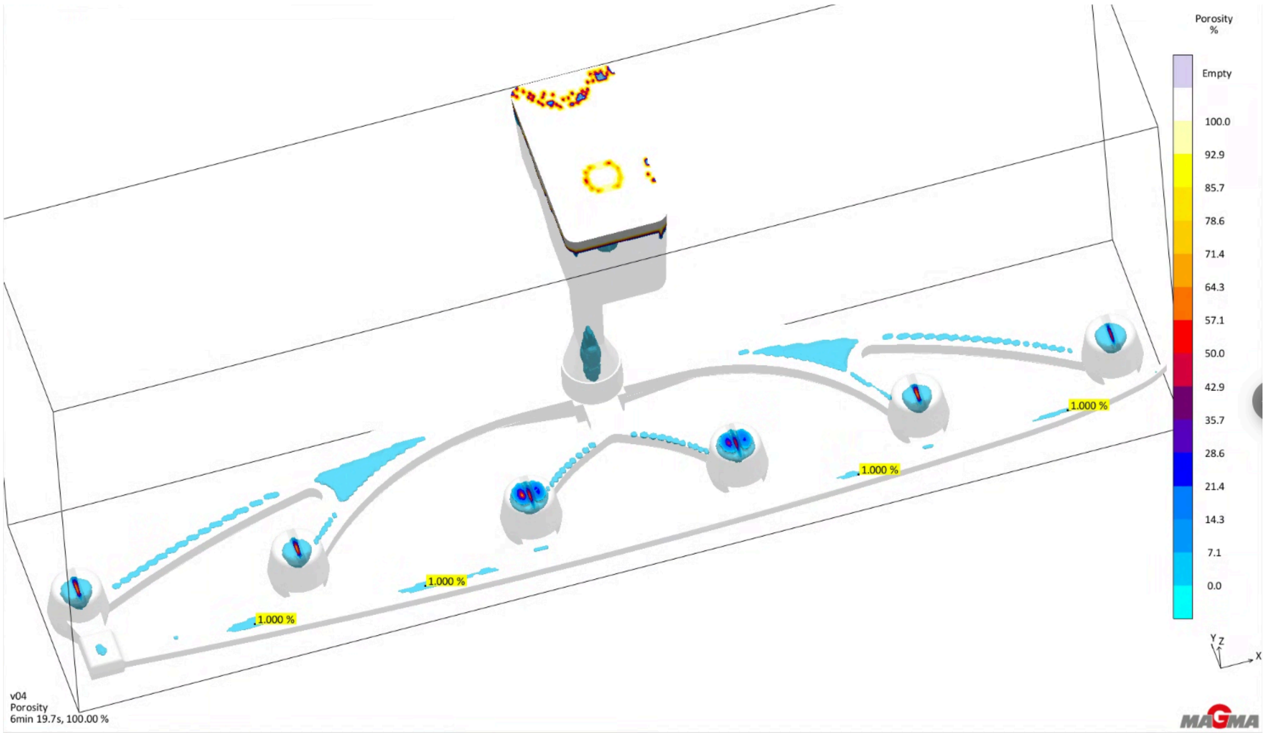

Figure 6. Total Porosity MAGMA simulation

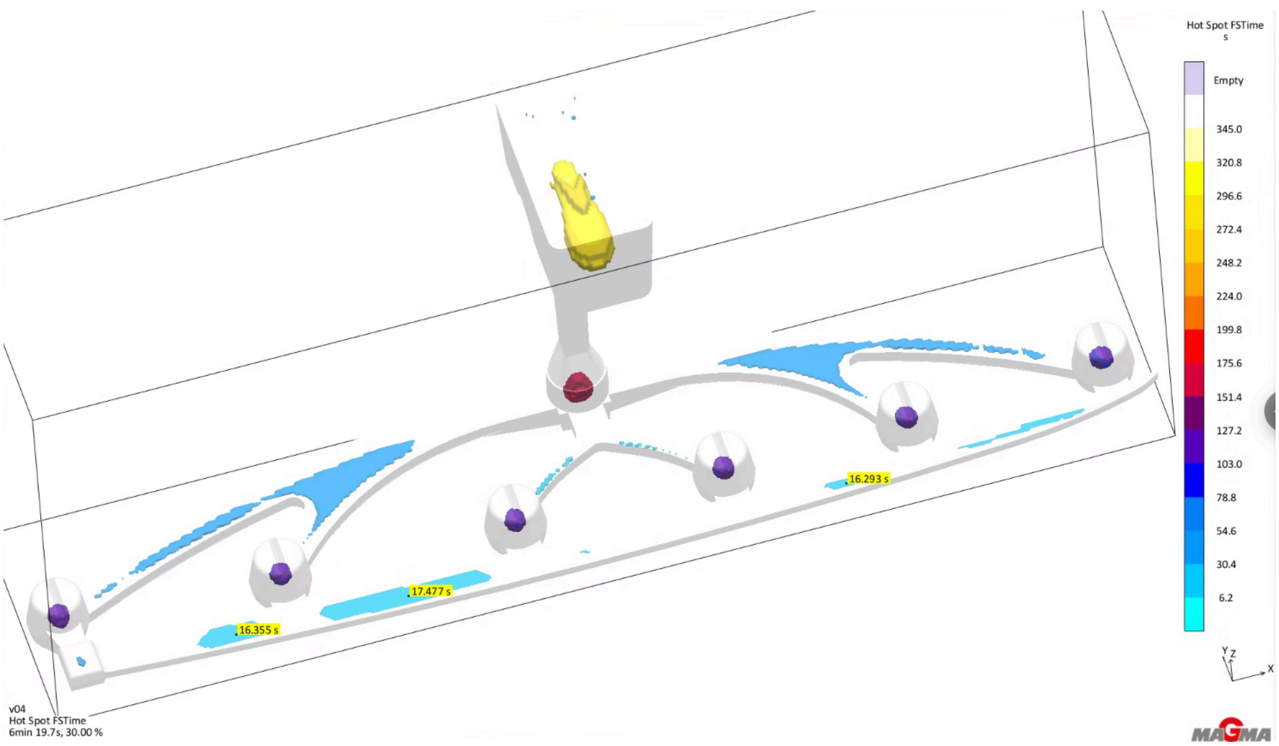

Figure 7. Hot Spot FS Time MAGMA simulation

3. Manufacturing

3.1 Pattern and Flask Production

The pattern of the sword and gating system was made using a fused deposition modeling 3D printer. The CAD file was split into multiple sections to accommodate for the printer bed size and allow quick replacement of damaged sections. Each section was coated with zip-slip to improve the removal of the pattern from the mold. Each piece was then assembled as a loose-piece pattern to be aligned with the flask during molding. The cope and drag flask was manufactured using ½ inch birch plywood. The flask was cut with a 5-degree draft angle to allow for ease of mold removal and was held together with 2-inch wood screws.

3.2 Sand Mold Production

The loose-piece pattern and flask were aligned manually and placed on a flat table. The mold was produced using no-bake sand with a 1.5% phenolic-urethane resin to sand and a 35% hardener to resin mixture. These mixtures were chosen based on manufacturer recommendation and previous success in molding. Prior to molding, two rounded pieces were added to the drag pattern to act as mold alignment features to improve mold assembly. The molds were allowed to sit overnight assembled to ensure the resin and hardening agent had achieved full strength and reduce any parting line gaps between the cope and drag. Nine vents were drilled in key positions where air entrapment or high pressure was likely as well as to help riser feeding. Figure 8 shows the locations of the drilled vents. Figure 9 also shows the sand mold curing with the pattern indention in the mold.

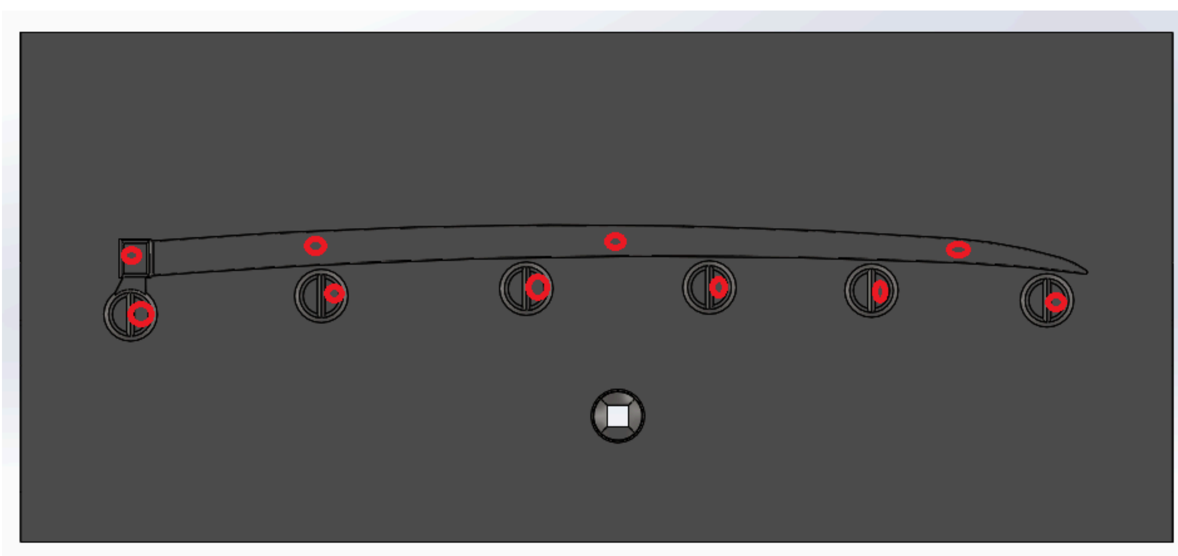

Figure 8. Location of drilled vents on the cope, as indicated by red circles

Figure 9. The mold curing in the flask before being removed and assembled with the pattern indention

The cope and drag then had the 3D print lines and connection points sanded and then cleared of debris using compressed air. Once smooth and clear of debris a zirconia ceramic foam filter was set below the downsprue. This filter will prevent any foreign particles from entering the casting during pouring. An acetone-based mold glue was applied on the drag before assembling the two halves. A downsprue extension was then glued to the cope with a pouring basin on top to provide the required head pressure for proper metal filling. One mold was made with plans to make more molds as needed if any failure occurs in the casting process and during post-processing. Figure 10 shows the assembled mold glued together and ready for casting.

Figure 10. The assembled mold lined up next to the induction furnace, ready for casting

3.3 Investment Casting Patterns and Shell Production

The guard and the pommel patterns were 3D printed using a low-ash PLA filament. and smoothed using 70% isopropyl alcohol. Patterns were then assembled into a tree which was then dipped in investment slurry. The slurry used is a water-based, fused silica investment slurry. The trees were coated with two zircon-based prime coats and six fused silica-based backup coats. This gives it enough strength to withstand burnout and prevent cracking during pouring and the solidification process.

3.4 Casting Process

The sand-molded sword was cast in-house at the Georgia Southern University foundry. The steel was melted in a 100-lb induction furnace under argon atmosphere and killed with aluminum during tapping. Molten steel was tapped at 3,150 °F and poured at an estimated 3000 °F. All personnel followed safety protocols to ensure a safe and efficient pour. Following pouring, the castings were allowed to cool in mold overnight. Figure 11 shows the liquid metal being poured into the mold in the university's foundry. Figure 12 shows the final casting after the casting had cooled.

Figure 11. The liquid metal being poured into the assembled mold

Figure 12. The final casting after an hour of cooling and the mold was shaken out

The guards and pommels were investment cast in-house at the Georgia Southern University foundry using our natural gas furnace. The investment shells were fired at 1562 °F for 1 hour before being allowed to cool in the furnace overnight. The shells were then cleaned of any debris before being preheated to 1652 °F prior to the metal being poured. While preheating, brass (78Cu-21Zn) was added to the crucible to begin melting. Once the melt reached 2012 °F, the investment shell was moved to the pouring deck. Once filled, the shell was left to solidify before being broken out.

Figure 13. The Investment shell is inserted into an empty crucible for stability

3.5 Post-Processing and Forging

The sword was removed from the gating system with an angle grinder. The surface of the casting was roughly ground using 40-grit sandpaper to remove the uneven surface. Once the surface is ground, the tang is heated in the forge to yellow hot before being hand forged to create notches in the surface to promote extension and hydraulically forged to reach the final shape and length. The sword was then shaped through grinding and sanding to reach the final desired shape. During shaping, a radius was kept on the transition from tang to sword to decrease the probability of shearing during testing. The fuller is then ground in following the blunt edge of the sword before the final polish was completed on the sword casting. The hand guard and pommel were cleaned up on a wire wheel before they were drilled and hand-filed to create a hole for the tang to be inserted. A hole was drilled on either side of the handguard inside the arms. One of these will become the attachment point for the chain while the other will have a sapphire added to both sides. A hole was drilled into the beak of the pommel to become an attachment point for the chain. Afterwards, the hand guard and pommel were polished and then placed in an ultrasonic cleaner with 50 ℃ water to remove residual polishing compound.

3.6 Heat Treatment Considerations

After casting, the sword was sealed inside an airtight stainless bag in order to minimize decarburization during the heat treatment. The swords were triple normalized by austenitization at 1700 °F for 15 minutes followed by air cool. This normalization cycle was to homogenize the as-cast grain structure, relieve the internal stress, and refine the grain sizes. Finally, the sword was directly austenitized at 1700 °F for 10 minutes, then quenched in non-agitated oil. A metallographic image (Figure 14) of a section of the sword shows the sword is fully martensitic. Finally, the sword was tempered at 400 °F for 60 minutes. This is to precipitate fine carbides from the martensite, forming a tempered martensite microstructure in the sword blade. Tempering time was selected by comparing the hardness and charpy analysis of the cast steel samples prepared from the heat.

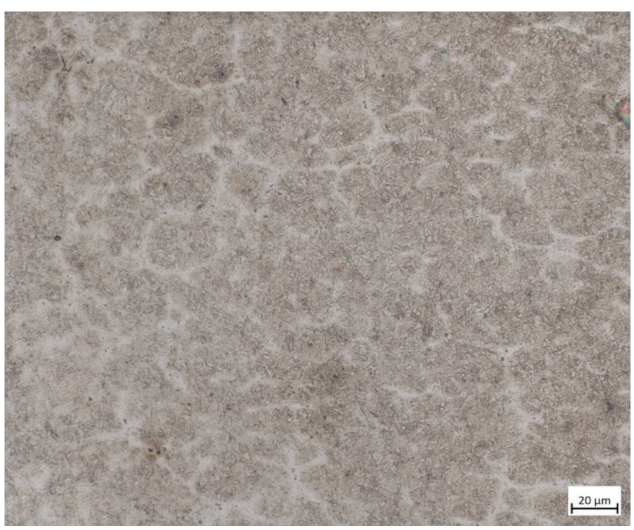

Figure 14. Microstructure of quenched sword showing fine lath martensite

3.7 Final Assembly

Once all parts were cast and post-processed, final assembly consisted of simply sliding the hand guard, handle, and pommel onto the tang of the blade and setting them in place with epoxy. After setting, the hand guard and pommel were connected with a bronze chain to complete the handle. The sword was given its final sharpening before being tested. The fully assembled sword is shown in Figure 15.

Figure 15. Assembled sword for the competition

3.8 Testing

The steel chemistry was measured with an optical emission spectrometer and a Carbon/Sulfur combustion analysis machine. The chemistry measured is listed in Table 1. The chemistry shows lower manganese and nickel than desired but otherwise meets the specifications for our modified 8630 steel.

Table 1. Composition (wt. %) of the steel

wt.%	C	Si	Mn	Cr	Ni	Mo	Al
Target	0.30	1.60	1.10	2.10	0.51	0.32	0.02
Actual	0.35	1.60	1.01	1.99	0.38	0.33	0.02

To achieve the optimum combination of hardness and toughness, the software JMatPro was used to calculate hardness and charpy impact energy at varying tempering temperatures. After analyzing both graphs, the team determined that tempering at 400 °F (204 °C) for 1 hour. The temperature and time were chosen to ensure the sword was fully tempered to achieve the desired combination of hardness and toughness. Figure 16 shows the hardness versus tempering temperature. Figure 17 shows the charpy impact energy versus tempering temperature.

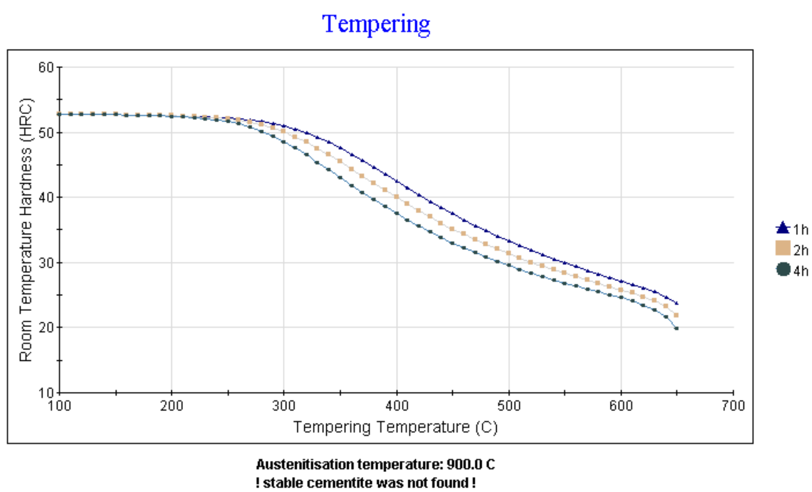

Figure 16. Room temperature hardness versus tempering temperature

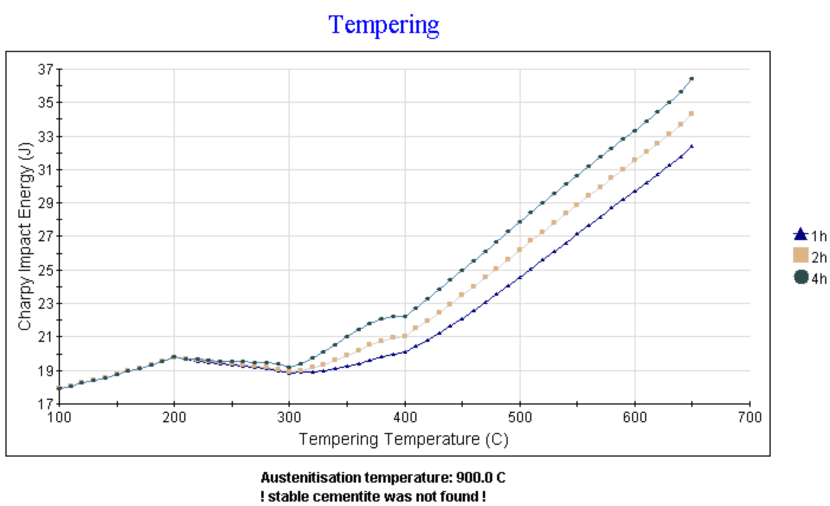

Figure 17. Room temperature hardness versus tempering temperature

The sword was tested by the student team by slicing and stabbing an assortment of boxes and fruit to simulate how this sword could have been used and to test the sharpness of the blade.

4. Executive Summary

The 2025 Cast in Steel competition, organized by the SFSA, aims to encourage students to explore the casting process and apply modern technology in creating steel products. Our team from Georgia Southern University designed and manufactured a sword inspired by George Washington's Silver Lion-Headed Cuttoe, a symbol of both status and military prowess during the 18th century. This report outlines the historical significance, design process, and final results of our project.

Historical Background and Accuracy

The cuttoe, a short, slightly curved sword, was a popular sidearm among Revolutionary War soldiers, including General George Washington. Our sword is based on Washington's Silver Lion-Headed Cuttoe, which he carried during his service in the Virginia Militia and the Revolutionary War. While our design incorporates elements from Washington's sword, such as the blade's curvature and the use of a fuller, we replaced the lion motifs with eagle depictions to symbolize American patriotism. The use of brass for the guard and pommel further connects the sword to the early days of the nation, as brass was historically used in sword-making. This blend of historical accuracy and symbolic adaptation ensures our sword is both authentic and uniquely American.

Design Process

Our sword was designed in four parts: the blade, guard, pommel, and handle, each produced using different casting methods to achieve the desired complexity. The blade was cast using a no-bake sand mold, while the guard and pommel were investment cast to capture intricate details. The blade features a 30-inch length with a fuller to reduce weight without compromising strength. The tang was forged post-casting to minimize porosity. The guard and pommel were adorned with eagle motifs, reflecting our national bird, and included our university's logo and team members' names. Extensive simulations using MAGMAsoft optimized the gating and riser design to ensure a high-quality casting with minimal porosity.

Final Results

The final sword measures 37 inches in length and weighs approximately 1.6 pounds. The blade is made from a proprietary steel alloy (0.35C-1.60Si-1.01Mn-1.99Cr-0.38Ni-0.33Mo) chosen for its hardness, strength, and toughness. The guard and pommel are crafted from brass, adding historical and symbolic value. The sword underwent rigorous heat treatment, including normalization, quenching, and tempering, to achieve a tempered martensite microstructure, ensuring optimal performance. Testing confirmed the sword's sharpness and durability, meeting all competition requirements.

In conclusion, our sword is a tribute to George Washington's legacy, blending historical accuracy with modern casting techniques. It stands as a testament to the craftsmanship and innovation encouraged by the SFSA competition.

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