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

Michigan Technological University -
The Steel Toed Boots

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Executive Summary

The Bailey silver and ivory hilted cuttoe, touted as George Washington's battle sword, is likely one of the most iconic and well-known swords that Washington owned and used during his life. The sword has several notable features that distinguish it from others owned by the first president. The famous green ivory handle inlaid with silver tape gives the sword its name, in addition to the recurve crossguard design that John Bailey is known for. The length of the blade is also distinct from others of its kind, being far longer at 30 inches. The Steel-Toed Boots' take on the sword features a 37 inch blade with a recurve crossguard replicating the original design. The handle is composed of oak wood with a copper wire inlay. The design of the sword differs from the original in the lack of a fuller in order to spare time, the lack of a curve in the blade to improve castability and solidification, and the variation in handle material as a cost-saving measure and to reflect the history of the college with the usage of copper, as the surrounding towns of Houghton and Hancock have a rich history in copper mining.

The design of the sword began with its selection. The Bailey cuttoe was selected for its unique look and castable design. Rough models were composed using Onshape software based on the known dimensions of the original sword. Further revisions were created to improve castability and compatibility with casting simulations run via Magma software. In tandem with modeling, alloy selection consisted of making a large list of steel alloys with desirable properties and comparing them using a series of material selection charts. The final alloy, 4330 steel, was chosen for its superior ductility and high toughness. A heat treating regime was then outlined with advice from Temperform. The ductility in 4330 steel is largely dependent on heat treatment, so this step was crucial in achieving the properties desired out of the final sword. The finalized regime consisted of annealing at 1750℉ to relieve residual stresses from the casting, then austenitizing at 1650℉ followed by an oil quench. Heat treating was completed by a further temper at 1200℉.

The final finishing work consisted of grinding excess material and scale from the blade and handle and adding an edge as well as handle design and fabrication. The handle was formed from an oak wooden dowel cut to size. The result was a full-tang cylindrical handle. Grooves were cut into the handle to accommodate the copper wire inlay added as a decorative measure.

Following the construction of the sword, material samples from the original casting and heat treatment were subject to optical emission spectroscopy (OES), tensile testing, and optical microscopy. These tests were selected specifically to compare the chemical composition, mechanical properties, and microstructural effects with that of what was predicted during alloy selection and heat treat design.

Introduction

The Steel Founders 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 year teams were tasked with either creating a replica of one of George Washington's swords or designing a new sword based on Washington's known preferences and needs. This report documents the steps that the team, The Steel Toed Boots, from Michigan Technological University took to replicate Washington's Bailey Silver and Ivory-Hilted Cuttoe. Background research on the history of the sword was the first step in the project, followed by alloy selection, the design process of modeling the sword design and casting simulation, the casting of the blades, heat treatment, and finally, the post-processing to finish the sword.

Background

History is often told through artifacts, like little snapshots of a time from the past. George Washington, the first president of the United States of America, grew a collection of swords over his years of service. The iconic painting *Washington Crossing the Delaware*, by Emanuel Leutze boasts this sword, but interestingly enough, the sword was not in Washington's possession at the time of this event [1]. It is estimated that Washington received the sword between late 1778 and 1779 in the Hudson Valley region. The green-stained ivory and silver tape that made up the grip was very fashionable in London and Paris in the early 1760s, sparking the inspiration for the aesthetic design of the sword. John Baily, an immigrant cutler from Sheffield, England forged the sword for Washington who wielded this sword during his time as commander of the Continental Army during the Revolutionary War [2].

The sword is not completely historically accurate in a few main ways; the first is that there is no upward curve at the tip of the blade. This change was made to hopefully increase the strength of the tip and reduce the chance of it breaking off when used. Removing this curve also allowed for better castability and a more uniform solidification. Additionally, a fuller was not ground into the blade as the team ran out of time to put one in. A change from the original sword is the use of copper wire rather than silver tape on the detailing of the handle. This choice was made to honor the history of the Keweenaw Peninsula, where MTU is located, adding a bit of personal flair to the look of the sword. The sword is accurate to the color and design of the handle itself. The overall shape of the guard is accurate to the original as well, minus some of the intricate details which were ignored in the model as it would add to the difficulty of the cast.

Design

The replica sword geometry was designed based on the known dimensions of the original piece and modeled in CAD software. The model was created in two sections: the blade and the guard (Figure 1). Dimensions for the blade length and total length of the sword were provided in the competition and image analysis was used in order to estimate the dimensions of the guard. As mentioned just above, certain simplifications were decided upon in order to improve the castability of the sword and its mechanical properties. The model was then sent to Temperform to have risers and gating added to the design and have casting simulations performed on the sword model. From the model, patterns were made by Temperform, and phenolic urethane "no-bake" sand models were used for casting.

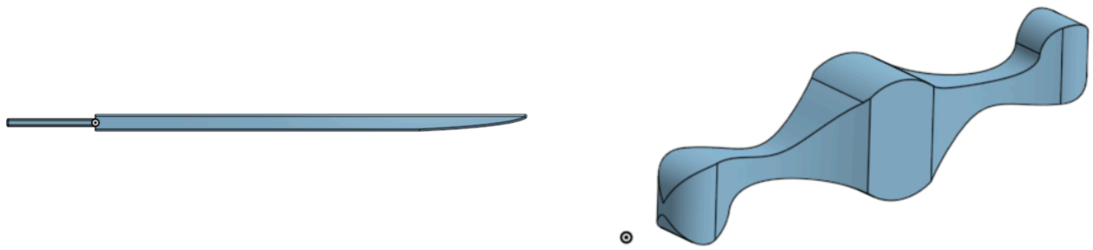


Figure 1. *The CAD models for the sword blade (left) and guard (right).*

The final selected alloy, 4330 steel, was chosen from a list of various steel alloys. Other alloys that were considered targeted high tensile strengths, high ductility, and good castability. Low-carbon steel was advised to maintain ductility, specifically with a composition targeted to be less than 0.4 wt% carbon. Ductility is desirable for the sword as it will allow for greater energy absorption and deformation under stress rather than breaking quickly. It is also important that swords are hard as they need to maintain a sharp edge and remain intact when under higher stresses. A 4330 steel alloy was chosen because of its high tensile strength, 860 MPa (125 ksi), and 15% elongation at break [3].

Table 1. *Summary of alloy selection.*

Material	Description
4330	Low alloy steel, Cr, Ni, Mb additions, more ductile than 4340
4340	Low alloy steel, Cr, Ni, Mb additions
5160	Cr, Mn alloy steel
8630	Cr, Ni, Mo alloy steel
1060	Medium carbon steel

The heat treatment was designed to austenitize, quench, and temper. For design considerations, temperatures between 500-1000°F were avoided due to the risk of tempered martensite embrittlement at this temperature range. Castings were heated to 1750°F (± 25°F) and soaked at that temperature for one hour, then subjected to a furnace cool to 1000°F. The temperature of 1750°F was selected in order to remove microsegregation from the casting, relieve any residual stress, and have a low enough temperature to avoid dissolving grain boundaries. After this, the castings were austenitized at 1650°F (± 25°F) for one hour followed by an oil quench. After austenitization, the casting was tempered at 1200°F and soaked at that temperature for two hours, followed by an oil quench. This temper was designed to increase the ductility of the blade. Based on the hardenability of the 4330 alloy, a Rockwell hardness of approximately 34 HRC was expected post-heat treatment, and strength was estimated to be between 105-150 ksi [4].

Fabrication

The mold for the sword was 3D printed using sand and resin layers. The molten metal was tapped at 3020°F and was poured at 2940°F. Once the swords were cooled, the castings were knocked out of the molds. However, during this process, the blades separated from the guard. The blades were welded back onto the guard prior to heat treatment, ensuring that no voids were present in the interface. The risers were cut off before the heat treatment process, but the gating was left attached to the swords in order to reduce the chance of the swords warping during the heat treatment.

After the sword was cast and heat treated, excess material left by the gating and risers was ground off as much as possible by the Temperform team. Once the swords were received by the MTU team, further grinding with an angle grinder and sand belt grinder was done to minimize excess material left on the hilt and blade. To sharpen the one-sided blade, the angle and sand belt grinder were used to bring the blade to a consistent point. A whetstone was then used for the final sharpening of the blade. To maintain the integrity of the guard, minimal grinding was done in the post-processing.

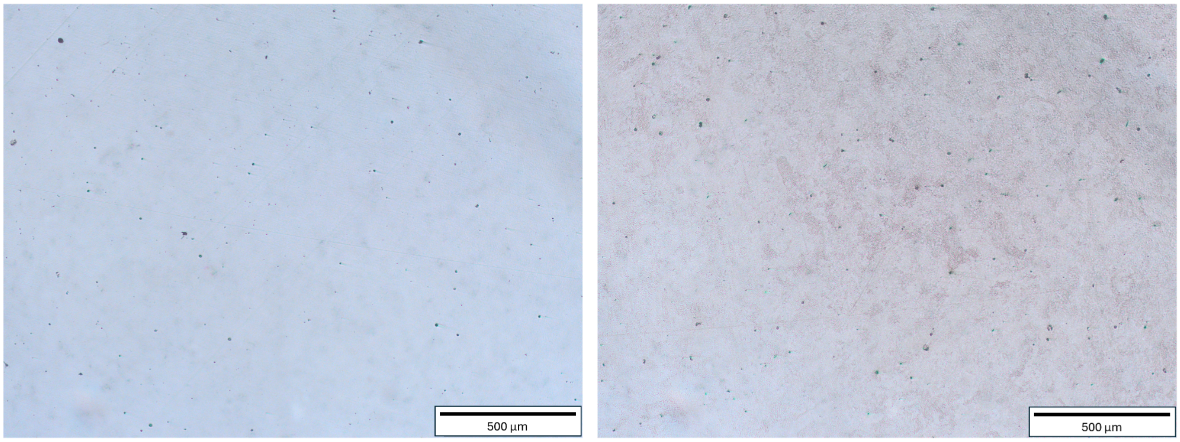
The handle of the sword was created separately from the cast blade. A wooden dowel with a diameter of 1.25in was cut to be 7in long. A 0.5 in hole was drilled into the center of the wood to the length of the sword's tang. To get the rough shape of Washington’s Bailey Silver and Ivory Hilted Cuttoe, wood carving tools, a pocket knife, and a disk sander were used. A wood dremel was then used to add more detail to the overall shape and create a crevice to inlay copper-coated steel welding wire to replicate the look of the silver tape seen in the original. Once completed, the handle was then fitted onto the tang of the blade with a hammer and a heavy-duty adhesive to secure it.

Inspection/Testing

In addition to the swords, test bars (with dimensions of 1x1x12in) were cast for inspection and testing. The composition of the alloy was measured using optical emission spectroscopy (OES) on an as-cast test bar (Table 2). The test bars were subjected to the same heat treatment as the sword, and the heat treated microstructure was observed using optical microscopy. Samples were sectioned from the test bar and cross-section polished using standard metallographic preparation techniques. Images were obtained using an optical microscope (Figure 2).

Table 2. *Composition of the sword alloy. figure*

C	Ni	Mn	Si	Cr	Mo
0.323 ± 0.002	1.53 ± 0.01	0.682 ± 0.01	0.433 ± 0.002	0.772 ± 0.002	0.183 ± 0.003



(a) **(b)**

Figure 2. *Optical images of sword alloy after heat treatment (1200°F temper). Microstructure prior to (a) and after etching with 3% initial (b).*

Standard ASTM-E8 round tensile specimens were machined from the as-heat treated bars and subjected to uniaxial tension testing at room temperature. The material was tested at a strain rate of 0.1 in/min and reported values are an average of 5 tests. The resulting stress-strain curves are plotted in Figure 3, and tensile properties are summarized in Table 3. The tensile properties fell within the expected range for the designed heat treatment, and the ductility was better than initially anticipated.

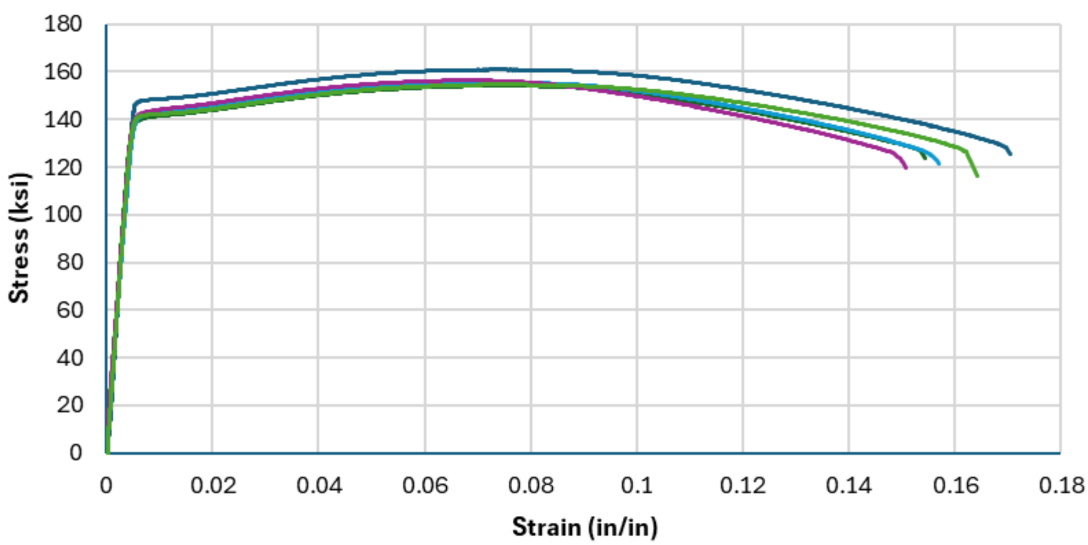


Figure 3. *Stress-strain curves for the sword alloy after heat treatment (1200°F temper).*

Table 3. *Summary of tensile properties for the heat treated condition.*

Yield Strength [ksi]	Ultimate Strength [ksi]	Elongation at Failure [%]
156 ± 3	143 ± 3	16 ± 1

Final Product

The final sword was 37 inches in length meeting the length requirement of being less than 43 inches in overall length. Additionally, it meets the weight requirement being approximately 1 kg. The sword is within 2 inches of the original sword length as the Bailey's Silver and Ivory Cuttoe was 36.125 inches in overall length with a 30 inch blade. The length of the replica's blade is approximately 30 inches as the handle is 7 inches. Just like the original blade, there is only one edge to the sword, additionally meeting the competition requirements. The-Steel-Toed-Boot's sword is well within the competition requirements. Figures 4 and 5 show the final replicated sword.

Figure 4. *Final replica of Washington's Bailey Silver and Ivory Hilted Cuttoe.*

Figure 5. *Close-up of the final replica's handle.*

References

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[2] S. Institution, "George Washington's Battle Sword and Scabbard," Smithsonian Institution. Accessed: Mar. 21, 2025. [Online]. Available: https://www.si.edu/object/nmah_434865

[3] "AISI 4330 Alloy Steel (UNS J24045)," AZoM. Accessed: Mar. 21, 2025. [Online]. Available: https://www.azom.com/article.aspx?ArticleID=6670

[4]"MTU Kehoe Sword HT Cycle Heat Chart Documentation", N. Knotts. March 2025