SFSA Cast In Steel 2025 - George Washington Sword Technical Report

Youngstown State University Team - George Washinguin

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Executive Summary

The Youngstown State University (YSU) team set out to design and manufacture a cast steel "George Washington Sword" meeting the style and utility of a late 18th century sword. 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 Youngstown State team worked with modern technologies and industry to create a cast sword fit for the first president.

The sword is most closely inspired by "The Bailey Silver and Ivory Hilted Cuttoe" from Washington's collection which he procured in 1978 or 1979. This is the sword displayed in the famous 1851 Emanuel Leutze painting "Washington Crossing the Delaware" and is the sword most associated with him as a battle sword. It is a single edge sword with a slight curve, resembling a hunting sword that came to be known as a cuttoe. It is suitable for both slashing and striking. The team opted to add a spine for additional strength with the cast steel. The original cuttoe from the collection has a blade length of 30", an overall length of 36.125". Our sword almost matches with a blade length of 30" and an overall length of 36". In the spirit of a casting competition, the team opted to cast a bronze hilt.

The team selected S7 shock-resisting tool steel for the blade material due to its high hardenability, high toughness, and slow transformation time. An 3D printed sand mold design was used where a printed valve was opened at a predetermined time to drain the riser and gating system to minimize post-processing. The team elected to over-mold a manganese bronze hilt onto the blade. The materials selected took into account performance as well as manufacturing process characteristics.

SolidWorks was utilized to design both the sword and the molds to prepare them for 3D Sand Printing. MAGMA casting simulation software was utilized to predict solidification times for each pour and determine if porosity or other defects would result from the mold design. The larger changes in mold design resulted from changes to make the pour easier, safer, and reproducible. Two mold sets were designed: one to make a set of blades, and the other to cast a hilt onto a blade. Extensive discussion surrounding heat treatment led to a targeted hardness of 48-52 HRC for the blade to produce a hard, tough sword that can retain an edge and flexibility without fracture.

The team gained insight into casting design, design for manufacturability, alloy selection, physical metallurgy, and industrial foundry practices. Our steel foundry partner was Trumbull Metal Specialties in Niles, Ohio and the bronze pour was conducted at Oakes Foundry in Warren, Ohio. The sand molds were printed by Humtown Additive and Youngstown Heat Treating did the heat treatment and tempering.

The final sword weighs 3.8 pounds and is 36 inches long, meeting the size and weight limits for the competition. Our testing indicates that this sword appears to perform well, and we are excited to see how it fares in the competition.

Table of Contents

1. Introduction

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 George Washington Sword competition creates a unique challenge of adapting casting to produce a traditionally forged object. The Youngstown State team recognizes the challenge and applied modern technologies and some innovative techniques to produce our George Washington inspired entry. Our goal was achieved by experimenting with two casting techniques we have not used before: Using a 3D printed sand mold with a valve to drain the riser and gating system of our blade mold and casting the hilt directly onto the blade by over-molding it.

The team started the design process early on by reviewing available resources for George Washington's sword collection. It was noted that in his time, swords were used more as a status symbol than they were used as a weapon. Since the sword requires functionality, we modeled our sword on the general form of the more battle-ready swords of the time. These swords closely resembled hunting swords: they are single edged and have a slight curve to allow for effective slashing. George Washington was tall and was noted to prefer a longer sword than was typical in his time. This distinct preference was incorporated into our sword. Following the inspiration for the sword's style, technical details of the design were addressed.

Blades can be damaged in use by fracture or becoming dull which can be highly dependent on the material selection and processing. Early on it was decided to use a castable tool steel to get excellent mechanical properties, primarily high hardenability and toughness with some flexibility. Additionally, many tool steels can be air hardened which simplifies the heat treatment process. S7 was selected for the blade for its high shock resistance, hardenability, and high toughness, as well as availability from our foundry partner. A desired hardness between 48-52 HRC to be hard enough to slice through obstacles but still flexible enough to avoid fracture. A manganese bronze was selected for over molding the hilt for its appearance and it fits the period. The dense copper-based alloy helps balance the sword to improve handling, is corrosion resistant, and readily wets to steel.

Our molds this year were not typical: our blade mold featured a valve to drain the filling system after solidification and our blade mold was designed to cast bronze directly onto the blade. Best practice casting principles were followed where possible, such as adding risers to control solidification gradients and minimizing air entrainment during filling. The use of 3DSP molds made the valve geometry possible. MAGMA was a useful tool for predicting the effectiveness of mold design changes and predicting solidification times for both castings. The general mold design didn't require much adjustment, but designing the molds for assembly and the safe operation of the valve by foundry workers did require a few iterations.

Our competition ready George Washington Sword falls within the competition requirements of being less than 40 inches long and weighing under 4.4 lbs.

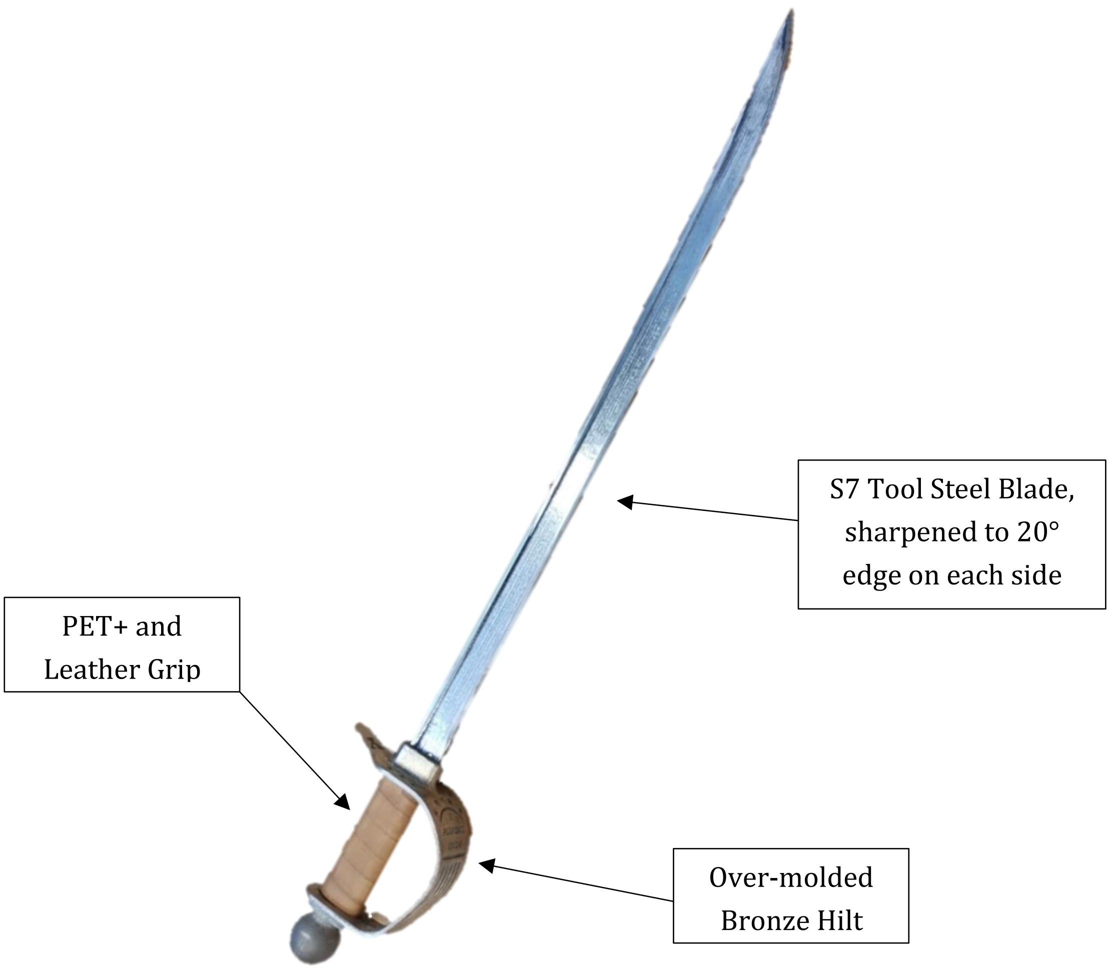
Blade Length: 30”

Overall Length: 36”

Final Weight: 3.8 lbs.

Blade Material: S7 Tool Steel

Hilt Material: Manganese Bronze



1.1. Team Members

The Youngstown State University Team, *George Washinguin*, consists of Mechanical Engineering students Coleman, Joseph, and Victoria, and Mechanical Engineering Technology students Ely and Elly. Our Team Advisor Dr. Brian Vuksanovich guided the team in casting techniques and Design for Manufacturing principles. The team name George Washinguin is inspired by the competition objective and the university mascot, the Youngstown State Penguins.

It's not easy for new designers to predict all the processing and tools needed for a concept to be realized. They also struggle to maximize the resources they have available. This competition develops both of these skills as the casting design is highly flexible and *should* change to best suit the processes that follow the pour. The team learned extensively about categories of steel alloys, designing castings to be easy to process, heat treatments, and the tools needed to finish the product.

This competition is a great opportunity for both engineering and engineering technology students to apply manufacturing, design, and materials science principles. The project also allows students to work with industry and see how an industrial foundry setting differs from the university foundry. The competition gives students an opportunity to build their technical skills and work hard on their entry, generating excitement about careers in the foundry and steel industries.

Figure 1.1: Team photo of the Youngstown State team for Cast in Steel 2025.

2. Sword and Hilt Design

This year a sword was selected to be produced for the Cast in Steel competition. Typically, swords are forged from stock – in the spirit of a casting competition, our sword is entirely cast except for the wrapping on the handle. This allowed us to produce a blade that is nearly net shape but must be processed properly to maximize its strength.

A previous Cast in Steel competition asked teams to produce a Celtic Leaf Sword, which differs from the style of a late 18th century American sword that would have been used by George Washington. Leaf swords concentrate mass toward the end of the sword to assist in cutting and are double edged, while British cuttoe swords were single edged and used for both thrusting and slashing. Despite also being a sword, the intended sword is distinct from the previous leaf sword. Upon further research, the following considerations were made to respect the authenticity and functionality of our sword.

2.1. Style and Authenticity

- **Style:** While George Washington was a fighter, he also used swords for style like many commanding figures of his time. The styles of swords changed every few years just like the expensive cars and watches in our time. Because of this, it is difficult to make a sword that fits each era of his life. Our blade's form is most closely inspired by the "The Bailey Silver & Ivory Hilted Cuttoe" from Washington's collection [1]. It features a knuckle-guard.
- **Form:** Our single edged sword that matches the style of a cuttoe. These swords could be stylish and practical. The blade is roughly 1" wide with a slight curve, typical of cuttoes from the time. The slight curve of the blade and the spine allow strength for slashing with being able to also strike a target.
- **Length**: George Washington preferred longer swords as he was tall. Typical cuttoes of the time were 24-27 inches in overall length, and military use swords in Britain and France ranged from 30-33 inches. George Washington was noted to prefer a longer sword of over 36 inches. The length of our sword is close to the Ivory Hilted Cuttoe, with a blade length of 30 inches and an overall length of 36 inches, a very small deviation from Washington's actual cuttoe (36.125" long, 30" blade).

Figure 2.1: Bailey Silver and Ivory Hilted Cuttoe, the sword style most closely reflected in our design [1]

2.2. Functionality and Strength

- **Function**: Aside from sharpness, a key area of functionality is the balance of the blade. After researching general sword design, it was determined that a balance point just 3-4 inches from the hilt is desirable. This makes the sword easier to handle, and a heavier sword might not feel as clunky.
- **Material**: The materials and metallurgy of swords have changed with time. In Washington's era, steel swords were used but not mass produced. It was well known before his time that a forged sword tended to be more formidable than a cast sword. Modern steel alloys and processing should allow a cast sword to be functional with some considerations for metallurgy and careful post-processing.
- **Hardness**: The team debated extensively about the desirable hardness for a sword. Many resources exist for hobby knife-making and fewer exist for hobby sword-making. Users commonly prefer hardness nearing 60 HRC for knives, but the longer sword blades experience much higher loads and impacts and need a level of flexibility that knives don't. Ultimately, the team settled on a hardness between 48-52 HRC to balance hardness and flexibility while retaining its toughness. Both determine the edge retention of the sword, and toughness will reduce the chances of the sword fracturing when striking a target.

2.3. Other Aesthetic Choices

- The hilt design is inspired by the revolutionary movement in the thirteen colonies that lead to independence for the United States. Thirteen debossed stars are displayed on the hilt alongside the United States de facto motto, E Pluribus Unum, also containing thirteen letters. The motto meaning "out of many, one" was closely tied to the independence movement and is still preset on the Great Seal of the United States today. The hilt was designed to fit a large hand nearly 4 inches wide.
- Some prototyping was performed with a 3D printer to get a feel for what would be a properly sized grip. A grip was staked onto the blade and wrapped in leather tape. Comfort while handling the sword is improved by the grip.

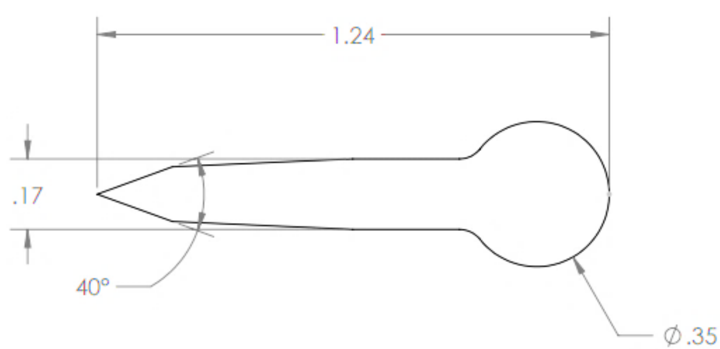


Figure 2.2: Designed blade cross section.

3. Casting Design and Process Planning

The design and manufacture of a casting requires foresight into the use of the product and the steps required to make the product functional. The sword is no different - when a process is thought to be straightforward, another consideration could change the design entirely. Many design changes were made throughout the year to adapt to the tools that were available and the desired final condition of the sword.

3.1. Alloy Selection

S7 shock-resisting tool steel is well known for its impact resistance and is commonly used in striking tools and shearing equipment. It's high strength and high hardenability are desirable for the blade. An advantage of using this tool steel over high carbon steels such as 1060 or 1070 is the ability to maintain toughness while achieving high hardness. S7 can be tempered to a hardness between 46-48 HRC, which is typical of swords. It can be hardened to nearly 60 HRC, but the team decided against this over concerns the edge would chip instead of becoming dull. In the interest of maintaining a sword, it would be more practical to be able to resharpen the sword than to replace it entirely. S7 has a low distortion when air quenched [2] – essential to maintaining the straightness of the blade between treatments.

Bronze was desired for the hilt for its appearance. Manganese Bronze was selected for its density to balance the steel blade as well as its appearance. Manganese bronze is also used in seawater environments [3], a testament to its corrosion resistance. The alloy is also one of the strongest commercially available bronzes and is castable.

Early in the process, the team considered other alloys. Maraging steel was considered to create an incredibly tough sword but ultimately was not selected due to inexperience with aging and the potential to over-age the sword - risking our ability to enter a competitive sword by the deadline. High carbon steels were considered but not selected due to concerns of brittleness in the cast material, and duplex stainless steels were eliminated from selection due to a complicated heat treatment to get desirable properties.

3.2. Casting and Mold Designs

It was decided early to use a binder jet sand mold for the casting, commonly referred to as a 3D Printed Sand Mold (3DSP Mold). This option is readily available to Youngstown State University through our partnership with Humtown. Our university also has access to MAGMA, a useful simulation software to compare casting designs and find improvements. 3DSP molds have great flexibility regarding design. Complex cores and gating can be reduced to shapes in CAD rather than maintaining a set of patterns. Additionally, molds are easily reproducible, and tooling adjustments are almost non-existent. This is beneficial, as a problematic casting design could be adjusted and reprinted within a day or two. For our small volume of molds, the 3D printed sand was ideal.

The blades were cast in a long pipe-shaped mold, with core inserts giving the blades their form as seen in Figure 3.1 and Figure 3.2. A valve made of the 3D printed sand was operated to dump the contents of the mold after the blades solidified. This was done to reduce post processing and remove a large amount of heat from the mold, reducing shrinkage defects. To determine a time to dump the valve, MAGMA was utilized to estimate when flow within the blades stopped. This was estimated with the fraction solid result shown in Figure 3.3 by expecting metal flow to stop near 35% solidification. For the valve to work, the larger riser section of the mold could not freeze before the blade. In our case, the blades were expected to freeze before the valve would become inoperable. The exact time of solidification was slightly off (30s was too frozen), but the temperature of the mold at pour was significantly lower than the simulated mold temperature explaining the discrepancy.

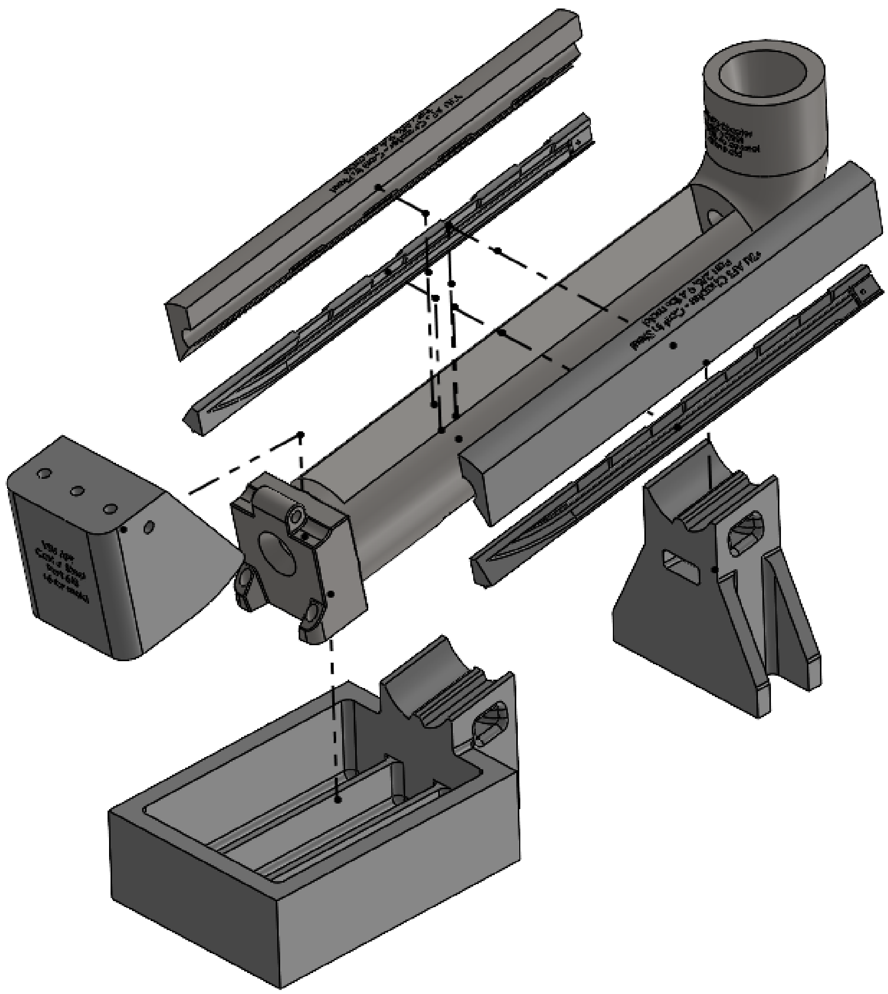


Figure 3.1: Exploded view of the 3D printed blade mold, 8 components.

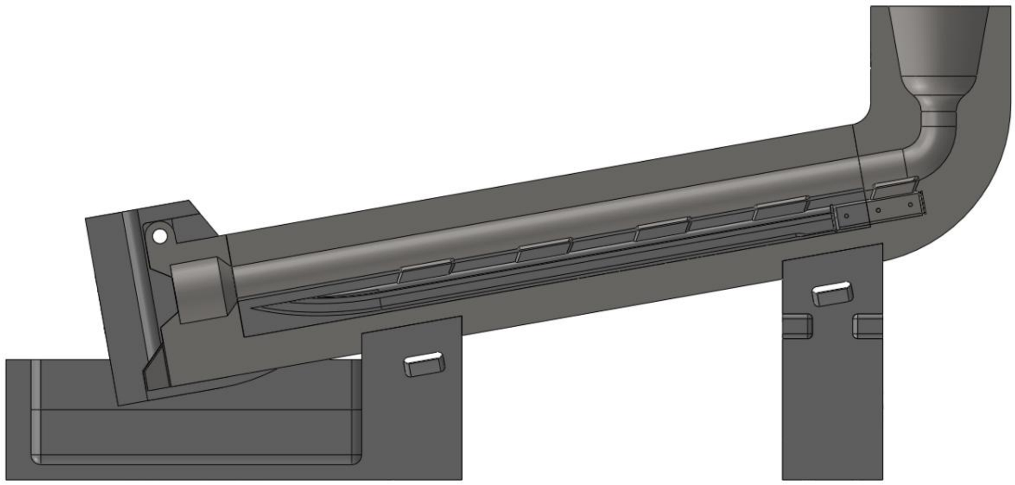


Figure 3.2: Section view of mold. The valve at the bottom is to be opened when the blades are solidified.

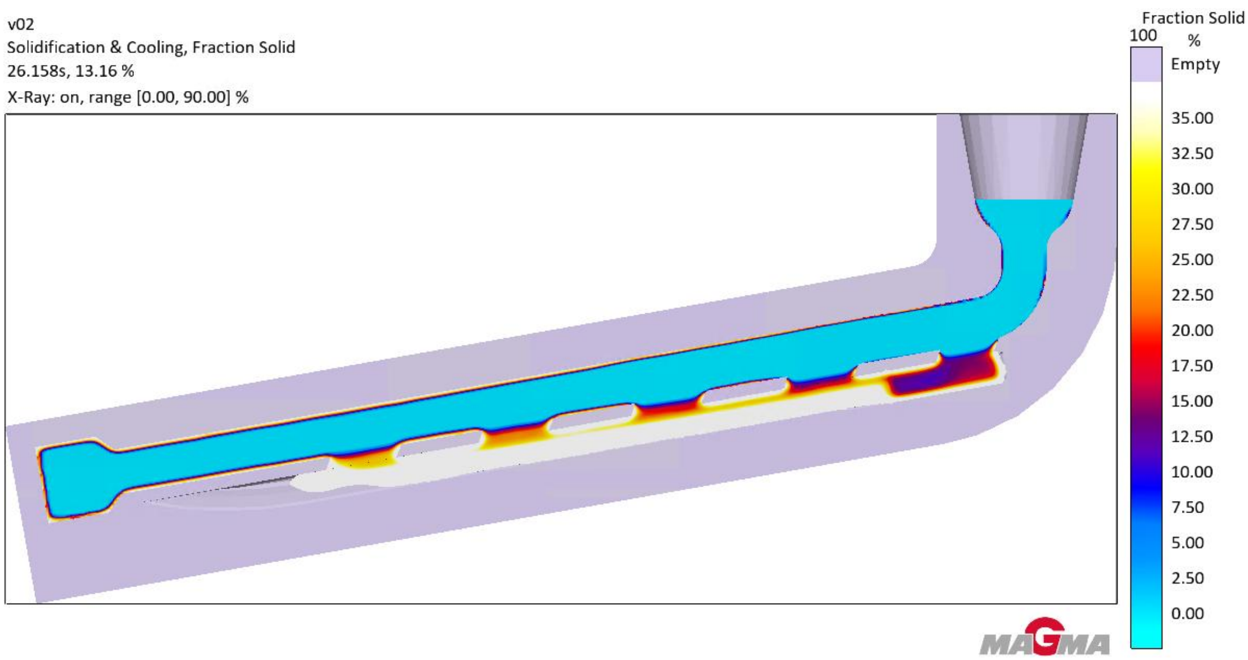


Figure 3.3: Fraction solid result at 26 seconds. The white areas in the blade indicate sufficient solidification (~35% solid) and flow has stopped enough to drain the riser.

The team decided to cast the hilt directly onto the blade (over-molding) rather than assemble it onto the blade. Ideally, this results in a hilt that is inseparable from the blade. This was a unique challenge that required careful planning to avoid delays, maintain the metallurgy of the blade, and prepare a mold that could fit the existing blade inside. The mold can be seen in Figure 3.4 and Figure 3.5, and later in Figure 4.7 and Figure 4.8

To avoid delays, the team focused on casting the blades before the hilt. The hilt mold design was finalized and sent out for printing while grinding and heat treating the blades. The blades had to be hardened and tempered before over-molding the hilt due to possible damage to the bronze during the steel heat treatment.

The hilt mold was designed to only cover the handle area of the blade. Flux was added to the handle of the blade to help the bronze wet to the steel. The mold and blade were supported above a column of water with the exposed blade area submerged to keep it cool. This was to prevent accidental damage to the blade heat treatment. The bronze was poured at 1900°F and held in the mold for 60 seconds while the thickest parts of the casting solidified. The mold was then turned over to empty the casting system of any remaining molten bronze and immediately broken open. The entire hilt casting was then submerged in water to cool it to minimize damage to the blade heat treatment.

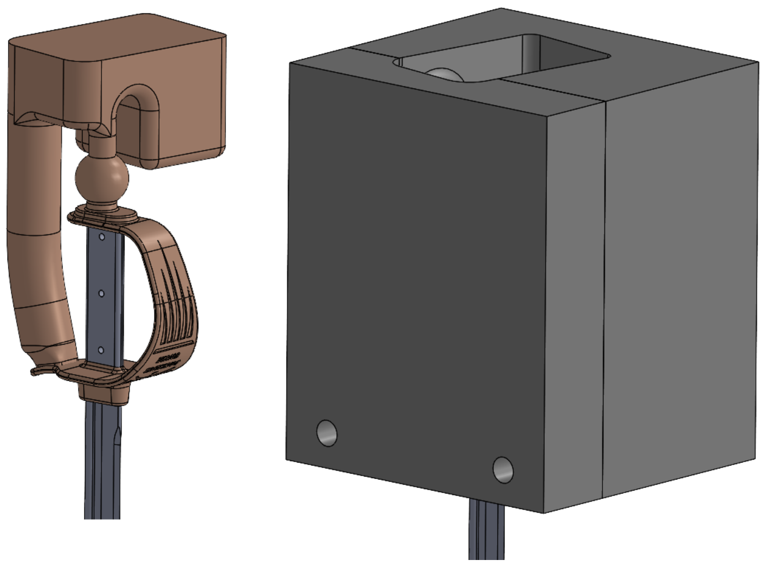


Figure 3.4: Hilt Over-mold - The holes in the mold are for rods to handle the mold when pouring.

Figure 3.5: Assembly of hilt mold showing internal cavity and cores.

MAGMA was used to verify sufficient filling of the hilt then predict the solidification time. After confirming the riser would solidify last, it was easy to observe when enough solidification had occurred by watching the riser feed the casting. The fraction solid simulation result at 45 seconds in Figure 3.6 closely resembles the produced casting shown later in Figure 4.9.

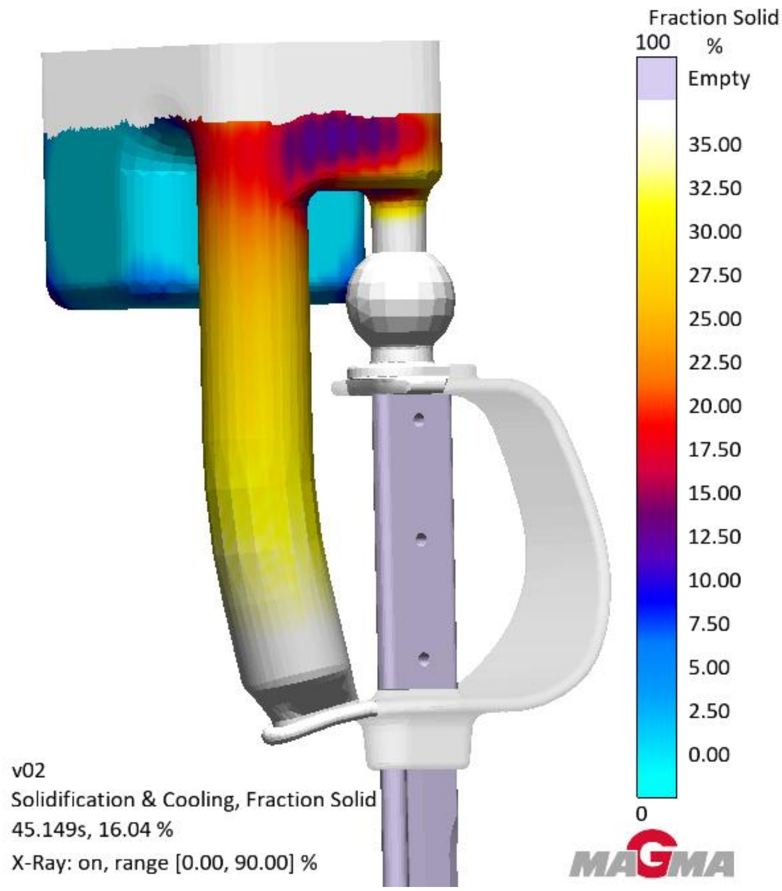


Figure 3.6: Fraction solid result indicates the hilt has sufficiently solidified by 45 seconds and flow has stopped. The remaining bronze can be poured out without material loss in the hilt.

3.3. Post Processing

Our mold design and casting plans are intended to reduce post processing. The remaining, minimal gating into each blade would simply need either cut off or ground off with abrasive tools. Sand blasting would be used after casting and between heat treatment steps to remove scale and surface impurities produced during each process, followed by grinding or sanding to clean the surface. Small pneumatic sanding tools and rotary tools were to be used for finer detailing on the hilt.

Lastly, the sword was to be decorated with a wooden grip staked on with brass pins, then wrapped in leather tape to improve comfort. After issues preparing the wood grip, a 3D printed PET+ grip was fit onto the handle. PET+ is known for increased flexibility and strength compared to ABS and PLA and should reduce the vibration felt through the handle. Steel roll pins would be staked onto the grip, and the grip was wrapped in leather tape.

3.4. Heat Treatment

One reason for selecting S7 tool steel was its simple heat treatment. There was no need for a dedicated quenching reservoir, as the alloy air hardens. A furnace accessible on campus was to be used for the heat treatment but additional help was sought to heat the blade in an inert atmosphere to minimize oxidation. Many conversations about the desired final properties for the blade took place during the design process and well into post processing.

The team consulted the ASM Manual for Heat Treatment and online resources to determine a heat treatment process. Many online resources were available for heat treating knives made of tool steels to achieve hardness exceeding 60 HRC, but the team determined a sword may find greater use with some flexibility and additional toughness. This is also observed with sword makers having issues with brittleness in high-hardenability carbon steel swords (1080 or 1090) and finding a good balance in hardness and toughness with lower carbon steels (1060 and 1070). The shock resisting steel benefits from carbide forming alloying elements that provide additional hardness while maintaining toughness.

The team determined that a high 40s HRC hardness was desirable for the blades after experiencing some issues processing the blades as-cast. As-cast, they were measured over 55 HRC. It was expected that this balance of toughness and hardness in the S7 tool steel at 48 HRC could produce a blade with excellent edge retention and minimize the risk of fracture during use.

Annealing the blade was predicted to take an entire day as the alloy needed to cool in a slow, controllable manner to avoid air hardening. Most of the time spent heat treating was spent controlling the cooling of the blade, rather than heating it. With little thickness, the blade did not require long soak times. After annealing, the blades could be straightened if needed. The risk of shattering the blades while handling and transporting them was minimized.

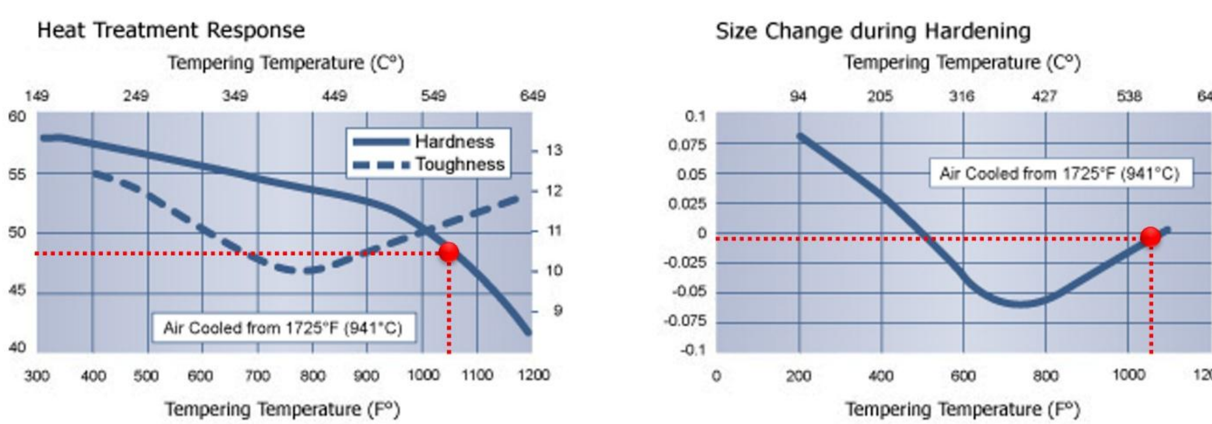


Figure 3.7: Tempering chart shows the hardness at the selected temper of 1050°F and minimal distortion during treating [4]

The hardening of the blade followed the standard hardening procedure for the alloy: preheating to 1450°F to avoid cracking the blade, soaking at 1700°F for 15 minutes, followed by air hardening. A double temper was then needed to improve the toughness of the blade. The team collaborated with Youngstown Heat Treating to determine the most suitable temper process based on the desired properties. Upon their recommendation, the team opted for a double temper at 1050 °F to achieve a 48-52 HRC. Hardness was to be recorded between each heat treatment step to verify if the desired properties had been obtained, as detailed in Section 5.1.

3.5. Inspection and Testing Plan

Heat treatment steps could be verified as successful by comparing to published hardness values. An automatic hardness tester was used to measure the Rockwell C hardness (HRC) between each step by indenting a flat polished portion of the blade. In the annealed condition, the HRC scale does not accurately represent or measure the hardness, and the Rockwell B scale must be used.

While processing the blades, the inspections made were primarily visual:

- Ensuring the blade remained straight and was not bent during heat treating, grinding, etc.
- Checking for cracks on the blades that could possibly be removed before spreading.
- Oxidation and then removal of observed oxidation.

When handling and assembling molds, inspections were made to improve the quality of the casting and ensure the safety of the student team and foundry workers:

- Verifying the molds fit as intended and do not leave gaps that could cause the mold to fail.
- Blowing loose sand out of the mold after each handling to minimize the chance of inclusions.
- Use of locating features and pins on molds and cores to aide in a well aligned mold.

Inspection of the finalized sword included:

- A polished finish on the blade and oil coating to prevent corrosion between shipment and the competition in April.
- A polished finish on the hilt and clearly visible detailing.
- A tested HRC between 48-52 on the blade.
- A uniform, sharpened edge.
- Proper packaging to prevent damage during shipping and ensure safety.

4. Production and Processing

After all the planning to produce the sword, the actual manufacturing and processing of the sword took place. The main steps of production were to first cast the blades, grind them to shape and heat treat, the cast the hilts onto the blades. The best sword was selected to be polished and sharpened for competition. The broken blades were used for testing processing methods and hardness measurements. They were also utilized for practical testing by chopping wood to verify the blades could withstand different degrees of impact. When the blade didn't shatter after accidentally striking a concrete shop floor, the team was satisfied with the strength of the blade.

4.1. Steel Blade Casting

Trumbull Metal Specialties in Niles, OH assisted the team in casting the blades. The entire team was able to attend the pour and see an industrial foundry environment. The team learned about the considerations to increase casting quality at mold assembly and adjust the pour to be safer for the foundry workers. Before assembly, the blade inserts were mold washed to increase the surface quality. The foundry was interested in our mold-dumping experiment. For comparison, one mold was dumped as planned and one was left with the riser intact as shown in Figure 4.3.

The S7 steel was poured into the mold over 6 seconds, then the riser was emptied 4 seconds later into an ingot mold at the base. The resulting blades shown in Figure 4.4 indicate the simulation results and plan to dump out the riser produced complete, straight blades requiring a minimal amount of grinding. In comparison, Figure 4.5 shows a blade that would require much more work to clean up and cracked from the additional heat remaining in the riser.

Figure 4.1: 3D sand printed blade mold parts before assembly.

Figure 4.2: Assembled blade molds, enough to pour six blades.

Figure 4.3: On the right, the mold has been successfully dumped into ingots with the sand valve. The second mold is being poured on the left and will not be dumped.

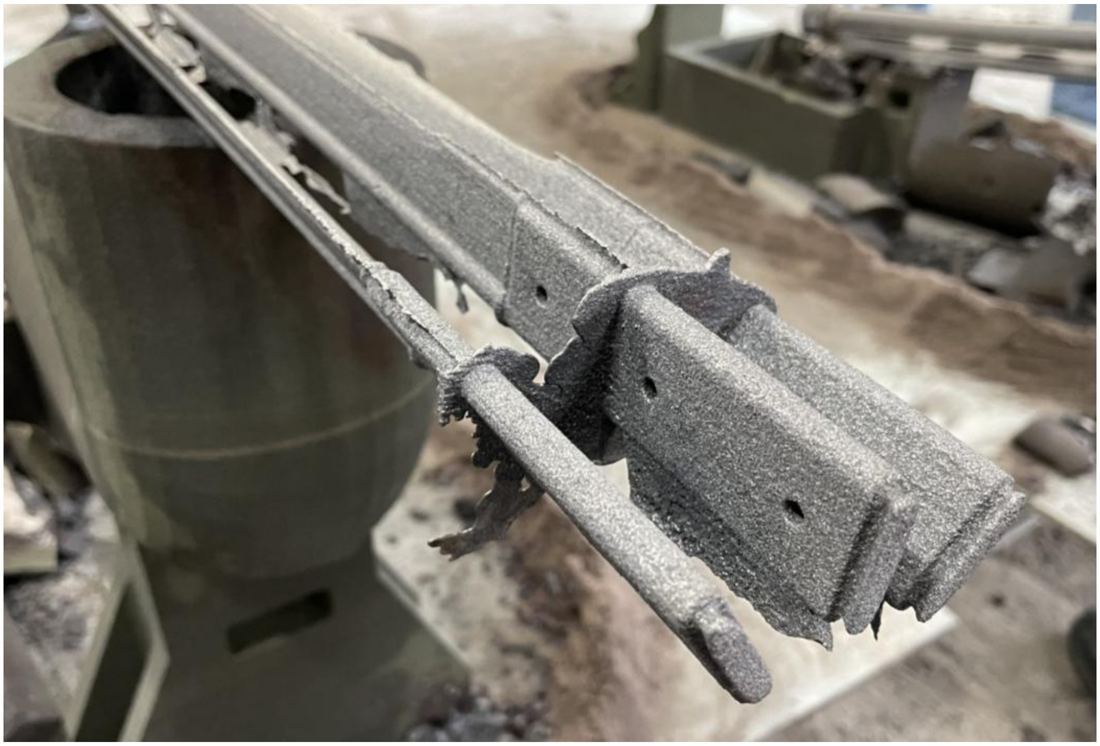


Figure 4.4: Three intact, straight blades requiring minimal grinding work from the mold that was dumped successfully.

Figure 4.5: On the mold that wasn't dumped, the riser contraction led to bending stress in the blade, causing a crack a few inches from the handle.

Figure 4.6: Blades during initial grinding to remove the remaining riser and gating material. On the top, three blades from the dumped mold. On the bottom, the blades from the mold that had not been dumped.

4.2. Bronze Hilt Casting

The bronze pour was assembled at Oakes Foundry. Pins were fit into the mold, and the mold was carefully assembled to ensure proper alignment for each blade. No gaps were present when the mold was clamped together, indicating that the mold and cores were well-aligned with the blade. Flux was added to the surface of the steel where bronze would be over-molded to help the bronze wet to the steel and minimize defects between the layers. A bucket of sand was used to support a PVC pipe full of water flush to the mold, and pipes were used to support the elevated mold shown in Figure 4.7.

After pouring, the blade remained the same temperature as the tap water in the pipe indicating that no transformation could have occurred in the useful region of the blade. The heating of the steel directly in contact with the hot bronze was minimized by breaking out and quenching the hilt casting as soon as the riser surface solidified. Risers were removed with a bandsaw and the ground with abrasive tools to reach the intended hilt surface. Large flashing sections were also removed, then the blades shown in Figure 4.10 were ready for final detailing work before testing and submission.

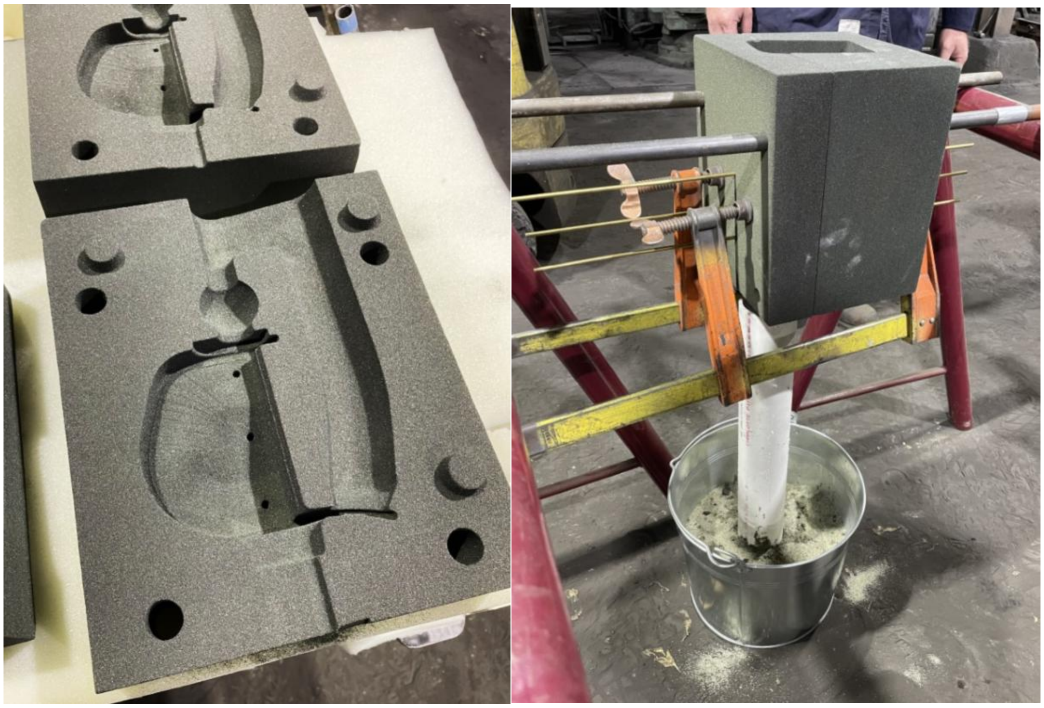


Figure 4.7: Hilt mold assembled for the bronze pour. The blade is sandwiched in the mold and contained within a column of water to minimize metallurgical transformation from heating.

Figure 4.8: Bronze about to be poured into the hilt mold.

Figure 4.9: As-cast hilt, broken out quickly and quenched to minimize changes to blade metallurgy.

Figure 4.10: Swords with all risers ground off, ready for details, polishing, and sharpening.

4.3. Finishing Touches

To finish the sword, the team needed to select the best sword to submit – originally, this was to be the straightest sword, but all three swords looked equally straight. The decision was then made by selecting the sword with the best potential edge.

The blade was given an initial sharp edge with a grinder. A finer edge nearing 20° on each side was obtained with a belt sander and sharpening was finished with a Tormek machine.

The team worked with smaller tools to remove flashing from the details on the hilt and rotary tools to polish the blade. A PET+ 3D-printed grip and leather tape were added to the handle for comfort and style. Lastly, the blade was sharpened, oiled, and ready for submission.

Figure 4.11: Removing flashing and cleaning out details on the hilt.

5. Results and Testing

Our resulting sword weighs 3.8 lbs. and is 36 inches long. The Youngstown State "George Washinguin" Team has worked with industry and applied the latest technologies to successfully create this sword. The blade has been polished to a desirable finish and coated with oil to minimize corrosion before the competition. All planned steps to process the sword were completed, and hardness was tested to verify the selected heat treatment was successful. The balance point of the sword lies just a few inches from the hilt, indicating a well-balanced sword.

The length and styling of the sword is fitting for George Washington's time. The single edge, spine, and slight curve of the cuttoe-style blade should make the sword to be suitable for slashing and thrusting into targets. The American Revolution theme of the hilt fits the period of George Washington's life he is most well-known for today.

Figure 5.1: The finished sword.

5.1. Inspection and Testing

The inspection plans throughout the process detailed in Section 3.5. were followed throughout, and a sword that was straight and had no significant defects was produced. To verify the heat treatment process, a Rockwell hardness testing machine was used on polished portions of the blade. The results are shown in Table 5.1. Careful heat treating, handling, and a casting method that reduced residual stress resulted in straight blades - no extra straightening was required. Additionally, the selected tempering temperature of 1050°F resulted in the least possible dimensional change and was clearly observed when no additional curve developed after heat treating. Alignment features in the hilt molds resulted in three produced swords with no discernible differences in the placement of the hilt relative to the blade.

Table 5.1: Hardness testing for the blades to verify heat treatment.

Condition	Expected Hardness	Average Measured Hardness
As Cast	Over 50 HRC	56 – 58 HRC
Annealed	91 HRB	89.6 HRB
Tempered (Handle Region)	48-52 HRC	48 HRC
Tempered (Blade Region)	48-52 HRC	44.1 HRC (see below)

The final and submitted blade was hardness tested, shown in Figure 5.3. An acceptable hardness of 49 HRC on the handle and 44 HRC on the spine indicate the correct heat treatment was completed. The 44 HRC measurement is likely lower than the actual hardness as the test was performed on the spine of the blade, nearly a convex cylinder. Hardness testing is intended for flat surfaces. The blade cannot resist the indentation as well from a lack of lateral support along the rounded edge. A correction factor [5] was used to estimate the effect of this geometry on the hardness referencing Figure 2.2, and the hardness is closer to 46-47 HRC. This is softer than the target range but not detrimental as flexibility is still desirable. A hardness test directly on the sharpened edge was difficult to perform with the testing machine and any damage to the edge was undesirable.

Figure 5.2: Weighing the final blade. (Recorded as 3.8 lbs. to consider any small additions to the grip)

Additional blades that were not finished but still fully heat treated were used for practical testing. Various pieces of wood were stuck with the sword both with and against the grain. As a bonus, unplanned test, the blade struck the concrete shop floor and survived. With no damage to the sword and clear damage to the destroyed wooden test pieces, the team is confident the sword has been prepared for competition successfully.

Figure 5.3: Rockwell Hardness Tester used to measure the final hardness of the handle and blade spine on the submitted sword. The result indicates the intended heat treatment was completed.

6. References

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