SFSA CAST IN STEEL 2025

George Washington Sword
Technical Report

University of Wisconsin – Platteville | Pioneers

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Executive Summary

SFSA created this competition encouraging students to learn about making steel products using casting process and applying the latest technology available. The challenges of the project presented by SFSA are creatively designing and producing an authentic yet practical replica of a sword for George Washington. An additional challenge was to include as much historical accuracy and detail into the sword. This was accomplished by creating a sword representative of blades on display on Mount Vernon's "Washington's Swords" (Mount Vernon Collections). A flattened lenticular blade was designed to match that of the original Alte Presentation Broadsword. Dimensions like blade thickness, length, and overall length were carefully abided by to produce as accurate of a replica as possible. The hilt was designed to appear the same as the original hilt, however instead of forming brass in areas around the handle, the hilt was designed to be a one-piece casting. The leather wrapping was made to appear identical to the original Broadsword yet improved on the comfort of the handle itself. Overall, producing a replica equivalent to the original on the outside, yet improved upon under the scenes was the desired outcome.

The casting process is meant to save time and labor by creating a casting close to final dimensions of our sword. The goal was producing a casting only needing heat treatment and polishing after degating. The sword's final dimensions came in at a total length of 39.25" (99.7 cm), a thickness tapering from .1875" to .085" (0.476 cm to 0.216 cm), and a width ranging from 1.75" to 1.0" (4.445 cm to 2.54 cm) with a shoulder width 1.75" (4.445 cm). The final weight of the entire sword is 2.9 lbs. A key component of the design is that the sword and hilt are two separate castings. The material cast for the hilt was C87850 Eco brass. The sword was cast from a modified AISI 5160 steel in the UW-Platteville Metals Manufacturing Lab by investment casting. Materials were supplied by MetalTek International. All processes were performed in-house. This sword was the largest dimensional investment casting ever poured in-house sharpening our manufacturing capabilities.

Literature Review

Origins of the Ceremonial Broadsword

The evolution of the German hunting sword, or Jagdschwert, reflects broader shifts in both weaponry and society, especially during the late medieval and early modern periods. Initially, the Jagdschwert was a practical tool born out of necessity. Early hunting swords were designed to handle the rigorous demands of medieval hunting expeditions. These swords featured single-edged, broad, straight blades, suited for cutting through dense underbrush or delivering swift, controlled strikes to large game such as boar. Their shorter blade lengths, typically carried from a hunting belt, were ideal for close quarters, allowing hunters to maneuver quickly and effectively. While they were often designed with guard, quillons, and knuckle guard, they never had the pas d'âne as seen on so many swords of the era, since this was a structure belonging only to fencing. The hilts were robust, built to withstand the force of combat and the demands of outdoor use. Functionality was paramount, and ornamentation was minimal. The sword's purpose was primarily utilitarian, used typically only for hunting and self-defense against wild animals. (Ffoulkes)

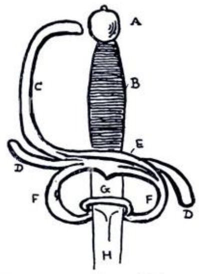


FIG. 47. A, Pommel; B, Grip; C, Knuckle-bow; D, D, Quillons; E, Counter-guard; F, Pas d'âne; G, Ricasso; H, Blade.

Figure 1 Graphic of sword anatomy. (Ffoulkes)

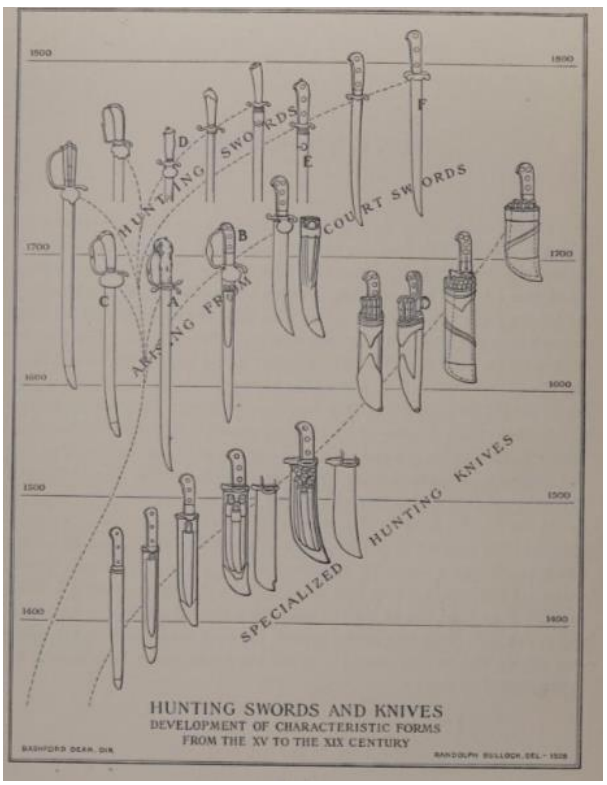


Figure 2 Chart featuring the evolution of hunting and court blades from the 15th to the 19th century. (MET)

However, the social and cultural changes that occurred in Europe from the late medieval period through the Renaissance and Baroque eras transformed the role of the hunting sword. As hunting evolved from a necessity for survival to a leisure activity for the elite, the design and functionality of the hunting sword began to reflect this shift. Nobles and monarchs sought to demonstrate their wealth, power, and military prowess not through practical weaponry, but through elaborate, symbolic swords. This shift marked the transition of the Jagdschwert from a utilitarian tool to a ceremonial object. (MET)

During the Renaissance, the broad, straight blades of the Jagdschwert began to evolve into more elaborate forms, reflecting the new demands of ceremonial use rather than combat. The transition from functional hunting knife to ceremonial broadsword can be traced to this period, where the blade, although still broad, became more refined, slightly more curved, and aesthetically pleasing. These swords were not designed for hunting but for display. Ornate hilts, often featuring intricate engravings, gilding, and sometimes precious gemstones, became standard. The pommels became larger and more decorative. The blades themselves were often engraved with intricate patterns, coats of arms, or symbols of the noble family to further assert the status of the owner. The Jagdschwert had become a symbol of nobility, an object that reflected the wearer's wealth, status, and finesse.

Figure 3 Detailed drawings of the engravings on a French hunting sword, a couteau de chasse. 1780. (MET)

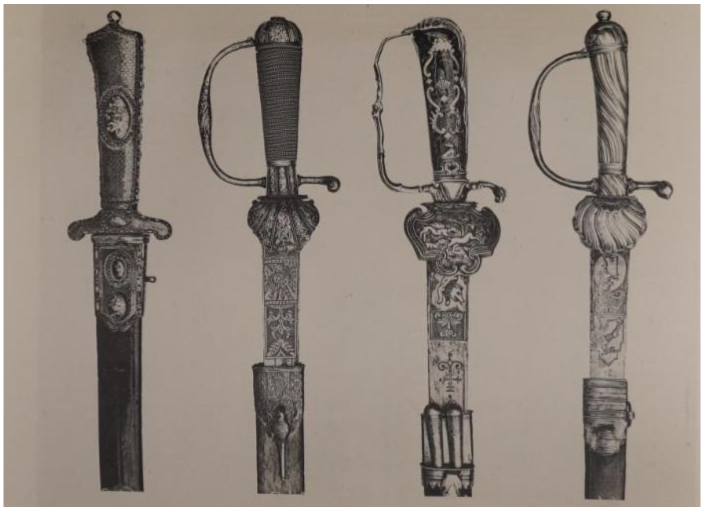


Figure 4 German and French hunting swords. 18th century. (MET)

The evolution of the German hunting sword into the ceremonial broadsword mirrored broader changes in European martial culture as well. In the 16th and 17th centuries, the battlefield was increasingly dominated by firearms and other gunpowder weapons, which made traditional swords less practical in combat. This shift in warfare made the functional sword a symbol of a bygone era, and with it came a greater emphasis on swords as symbols of valor and nobility, rather than as tools of actual combat. The former practical aspects of the Jagdschwert—its broad, single-edged blade—remained as a reminder of its hunting origins, but its use had transformed into one of status and pageantry. Cavalry broadswords also played a significant role in this shift. These swords, which were designed for cavalry combat, were similar to ceremonial hunting swords but tended to be longer. Like their counterparts, cavalry broadswords became increasingly ornamental over time, evolving into symbols of nobility and martial honor. By the late medieval period, the cavalry broadsword, like the Jagdschwert, was less of a practical weapon and more of a ceremonial piece.

The ceremonial broadsword's design often reflected these dual purposes. While the sword retained much of the practical design of the earlier Jagdschwert—such as the broad blade—its purpose was now symbolic rather than utilitarian. The sword became associated with the ideals of chivalry, martial honor, and the noble class. It was often seen in formal events or ceremonial settings and was a necessary part of a nobleman's attire. The ceremonial broadsword was not necessarily a weapon of war anymore, but a signifier of cultural and social values. This transition from a tool of necessity to a ceremonial object also represented the broader cultural shift from the combat skills necessary for gaining political power to a focus on refinement and personal display as a means of personal gain. As swords were no longer primarily used for battle, the focus shifted toward aesthetics, craftsmanship, and the symbolic power they represented. The decorative broadsword embodied these values, illustrating how a weapon could transcend its original purpose and become a statement of identity and social standing. (Neumann)

Prussian-American Relations During the Revolutionary War

To first look at King Fredrich of Prussia's relationship with the American colonies, we must look towards his relationship with the British. Frederick the Great held a deep animosity toward the English government for failing to honor the support promised by William Pitt, the first earl of Chatham. During the American Revolution, Frederick was falsely accused by the English ministry of obstructing England's efforts to hire a Russian corps for the war and of permitting Prussian officers to serve with the Americans. These unfounded charges reflected England's fear of Frederick seeking revenge for past grievances. Neither Baron von Steuben, a German-born officer who played a pivotal role in transforming the Continental Army into a well-trained and professional fighting force during the American Revolutionary War, nor Johann de Rabais, a German-born French officer who served as a major general, were in Frederick's service when they volunteered for the American Revolution. Along with other German officers who joined them, they did so according to their own free will without King Frederick's endorsement.

The King of Prussia was looked on as the most capable sovereign and soldier in Europe, and his heroic struggle was pointed out as an example for America in its war for independence. George Washington, Benjamin Franklin, Nathaniel Greene (a highly regarded colonial militia officer) all spoke of him with admiration. Thomas Jefferson spoke of his death as a European disaster and as an unfortunate event that affected the whole world. Frederick wrote to his brother to watch Washington and learn how he fought against the British. He granted the request of the Americans to buy arms in Prussia. He may have unintentionally provided an even greater service by denying permission for German soldiers, on their way to join the English army in America, to pass through his lands. This delay in reinforcements, ended up benefiting the Americans. By preventing these German troops from advancing, he kept them stationed in Germany throughout the winter of 1777-78, during which Washington and his small army endured hardships at Valley Forge. The King wrote in October 1777," His Majesty has refused passage to the

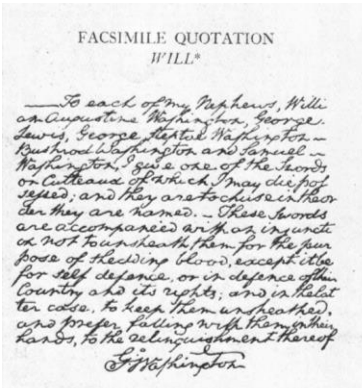
Figure 5 Lithograph of Fredrich the Great, King of Prussia. As depicted by the portraitist Kaulbach. (Rosengarten)

auxiliary troops of Germany destined for America. He interests himself very much in the events of your war and wishes that your efforts may be crowned with success." (Rosengarten)

Gifting of the Alte Presentation Broadsword

In 1795, an artisan named Alte from Solingen, near Düsseldorf, crafted the Alte Presentation Broadsword to symbolize the strong relations between Prussia and America, sending it with his son to present it to President Washington as a gift. (Mount Vernon) His son brought it to Philadelphia, as Washington was living there as President at the time, and pawned it in a tavern, "where it was redeemed by some unknown person, who took it to Alexandria, whence it was sent to Mount Vernon. Washington never knew who this was.

He writes to John Quincy Adams, Philadelphia, 12 September, 1796: " Some time ago, perhaps two or three months, I read in some gazette, but was so little impressed with it at the time (conceiving it to be one of those things which get into newspapers nobody knows how or why) that I cannot now recollect whether this gazette was of American foreign production, announcing that a celebrated artist had presented, or was about to present, to the President of the United States a sword of masterly workmanship, as an evidence of his veneration, etc. I thought no more of the matter afterwards until a gentleman with whom I have no acquaintance, coming from and going to I know not where, at a tavern I never could get information of, came across this sword (for it is presumed to be the same) pawned for thirty dollars, which he paid, left it in Alexandria, nine miles from my house in Virginia, with a person who re- funded him the money and sent the sword to me. This is all I have been able to learn of this curious affair. The blade is highly wrought and decorated with many military emblems. It has my name engraved thereon and the following inscription, translated from the Dutch: 'Condemner of despotism. Preserver of liberty, glorious man, take from my son's hands, this sword, I beg you. A Solingen.' The hilt is either gold or richly plated with that metal, and the whole carries with it the form of a horseman's sword or long sabre. The matter, as far as it appears at present, is a perfect enigma. How it should have come into this country without a letter, or an accompanying message, how afterward it should have got into such loose hands, and whither the person having it in possession was steering his course, remain as yet to be explained. Some of these points can only be explained by the maker, and the maker is no otherwise to be discovered than by the inscription and name, 'A. Solingen,' who, from the impression which dwells on my mind, is of Amsterdam. If sir, with this clew, you can develop the history of this sword, the value of it, the character of the maker, and his probable object in sending it, you would oblige me and by relating these facts to him, might obviate doubts which otherwise might be entertained of its late reception." (Sparks) Washington, who highly valued his swords and their symbolism, outlined the responsibilities of his heirs regarding the swords in his will and specified the order in which they should be chosen. Wherein George's nephew George Smallfoot Washington selected the Broadsword, and it remained in his possession until his untimely death from tuberculosis at age 37. The one sword not left to this process was instead personally given away before Washington's death, is the Morristown Museum sword. George gave it to his older half-brother Lawrence Washington sometime between the 1789 inauguration, when Lawrence was twelve, and the General's death in 1799. (Peterson, Lindsay)


FACSIMILE QUOTATION
*WILL**

—To each of my Nephews, William Augustine Washington, George Lewis, George Steptoe Washington—Bushrod Washington and Samuel—Washington, I give one of the Swords or Cutteaux of which I may die possessed; and they are to chuse in the order they are named.—These Swords are accompanied with an injunction not to unsheath them for the purpose of shedding blood, except it be for self defence, or in defence 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
G° Washington

Figure 6 Except from George Washington's will bequeathing swords to his nephews. It reads "to each of my nephews, William Augustine Washington, George Lewis, George Steptoe Washington, Bushrod Washington and Samuel Washington, I give one of the swords or cuttoes of which I may die possessed; and they are to choose in the order they are named. These swords are accompanied with an injunction not to unsheathe 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 latnter case, to keep them unsheathed and prefer falling with them in their hands, to the relinquishment thereof." (Lindsay)

Metallurgy

Mechanical Properties

Mechanical properties are essential to the performance of our replica broadsword. Properties like the hardenability of the steel, hardness, toughness, Young's Modulus, tensile strength, and the elasticity of the steel will have a major impact on testing. Hardenability is a measure of the steel's ability for form martensite. Very hardenable alloys will form martensite readily, capable of fully hardening in a slow cooling rate that can be provided by ambient temperature air. Alloys that are not very hardenable may never form martensite, even with a very severe quenchant like a brine solution. The carbon and alloy content of the steel directly impact the hardenability of the steel.

Hardness is very different from hardenability, as it is a measure of a material's ability to resist penetration. Very hard materials will not deform easily, unlike their soft counterparts. Hardness is directly related to the carbon content of the steel. Toughness often goes hand in hand with hardness as an inversely proportional relationship. Toughness is gained by tempering, which transforms brittle martensite into tough tempered martensite. In the event that the material was not converted to 100% martensite, retained austenite is left in the matrix. Retained austenite can be detrimental to load bearing parts, as energy inputs in the forms of stress, vibration, or heat can produce the phase change from retained austenite to untampered martensite. Without a second tempering cycle, the untempered martensite can lead to catastrophic failures.

Other critical mechanical properties include Young's Modulus, which provides insight on how stiff a material is. Tensile strength is a measure of a material's resistance to tensile forces. Elasticity defines the elastic region of a material, or the ability of a material to deform without permanent consequences. The combination of these three properties can provide significant insight into how well a material will respond to static and dynamic loads.

Figure 7 depicts AISI 5160's hardness vs toughness compared to other steels exhibiting similar mechanical properties. Using this figure, it can be determined that AISI 5160 is a good starting point for alloy selection, providing very high toughness values for high hardness values. Figures 8 and 9 provide data to determine the optimal austenitizing and tempering temperature. An austenitizing temperature of 1525^0F and a tempering temperature of 375^0F yield a hardness value of 59.5 HRC and an unnotched toughness of 44.6 ft*lbs. With this information, the heat treatment recipe was determined.

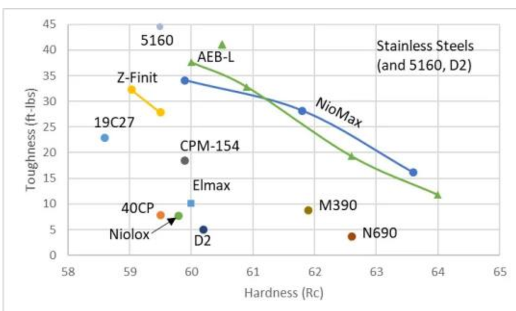


Figure 7 Commonly used knife blade alloys (Larrin)

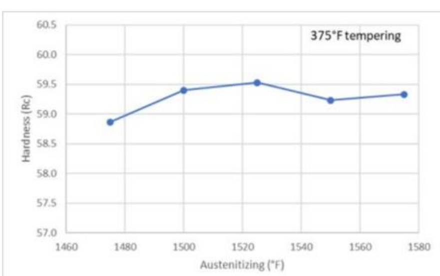


Figure 8 Hardness vs. Austenization temperature (Larrin)

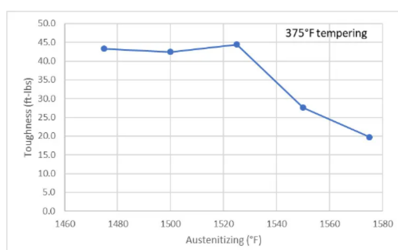


Figure 9 Toughness vs. Austenitizing Temperature (Larrin)

Chemical Properties

Figure 10 shows AISI 5160 used as inspiration to decide our chosen alloy composition as seen on Figure 11. Note the decrease of sulfur content from 0.04% down to 0.005% sulfur content to decrease sulfur inclusions. Chromium content was increased from 0.9 % to 1.003% to increase hardenability. Nickel was also added to increase toughness values.

Component Elements Properties	Metric
Carbon, C	0.56 - 0.64 %
Chromium, Cr	0.70 - 0.90 %
Iron, Fe	97.085 - 97.84 %
Manganese, Mn	0.75 - 1.0 %
Phosphorus, P	<= 0.035 %
Silicon, Si	0.15 - 0.30 %
Sulfur, S	<= 0.040 %

Figure 10 AISI 5160 Steel 1500˚F Annealment Element Properties (Matweb)

C	Si	P	Mn	S	Mg	Cr	Cu	V	Ce	Nb	Al	Mo	Ni	Ti
0.603%	0.289%	0.019%	1.05%	0.005%	0.00%	1.003%	0.107%	0.009%	0.008%	0.002%	0.085%	0.023%	0.530%	0.029%

Figure 11 UWP Modified 5160 Composition

Process

Sword

Design

Upon initial examination of all possible swords to create for this competition, one stood out as the most castable while still performing during the testing, the Alte Presentation Broadsword. Creating a replica of this blade was accomplished early into the process. Designing the sword for manufacturability specific to UW-Platteville's foundry is where things became difficult. The first roadblock our team encountered was ensuring enough material filled out the blade edge during solidification of the investment casting process. To accommodate this, a cylindrical boss was created along the cutting edge of the sword. This boss also would allow for decarburization to occur, without jeopardizing the hardenability of the blade's edge. The next hiccup was encountered when looking at our 200-pound ferrous induction furnace. The maximum mold or shell height we can pour out of this furnace is 30 inches from the floor. To resolve this issue, we elected to design a pouring basin that sits parallel to the floor when the shell tilted to make a 30^0 angle with the floor. We would then hand-ladle molten steel from our induction furnace to the shell which would be resting on a cart and pour the casting. The use of a down sprue was necessary to avoid directly pouring into the casting itself as we feared the possibility of the molten metal freezing off. Due to this, our casting was on top of the down sprue/riser combination. For solidification purposes, we needed to tilt the entire cart and shell combo vertically. Figures 28 and 29 depict the necessary steps described for our pouring procedure. The simulated porosity of vertical solidification of the sword with defined pouring temperature and shell preheat temperatures at 2950^0F and 2000^0F respectively can be seen in Figure 12.

Figure 12 Vertical solidification of the sword

Castings should be designed to be near-net shape to be an effective means of manufacturing. With this in mind, a cross-section of our sword can be seen in Figure 13. It can be observed that the cross-section of the blade was designed to have a flattened-lenticular shape, a common and effective shape for swords. At its thickest, where the bolster ends and the blade begins, the thickness of the sword is 0.1875”. At its thinnest, the sword was designed to be 0.085” thick, tapering down to the cutting edges. To win a competition like this, limits need to be pushed, which is why our team elected to make this sword as thin as possible while still holding up to the tests.

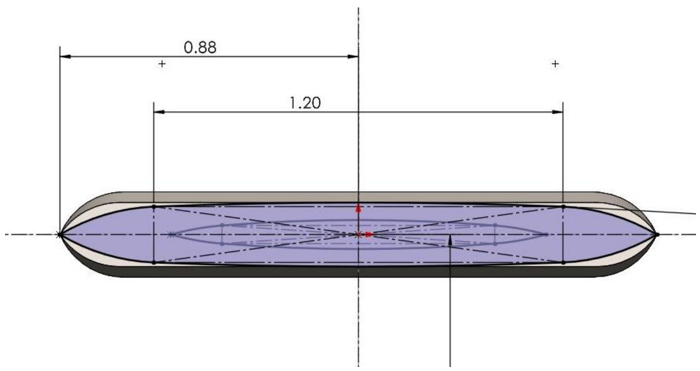


Figure 13 Cross-section of sword at blade hilt interface

Casting

1. The sword started with a 3D design and proper gating to effectively feed the casting

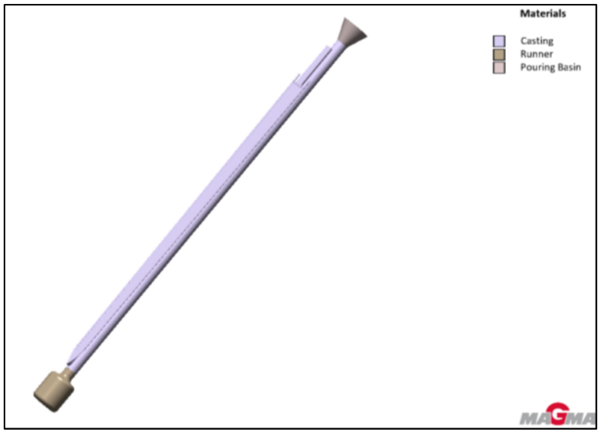


Figure 14 CAD Model of Sword

Figure 15 3D Printed resin wax pattern to be cast in silicone

2. A silicone mold was made to cast the investment wax into

Figure 16 Separating the silicone mold

Figure 17 Pouring wax into the Silicone mold

3. Cast investment wax parts and 3D printed parts of the gating were waxed welded together

Figure 18 Assembling the wax pieces

Figure 19 Wax Welding

4. Tape covered the pouring basing location and coated with slurry. The ceramic covering the tape will later be cut out for the pouring basin, allowing removal of the steel rod.

Figure 20 Final wax Pattern

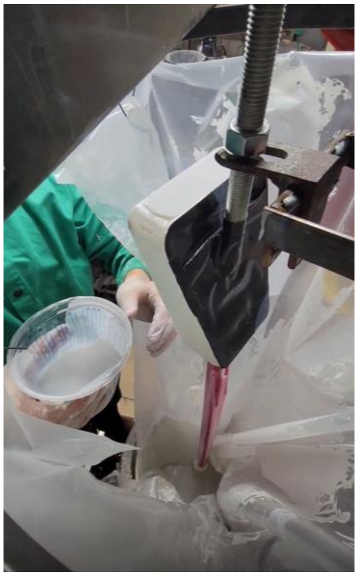


Figure 21 Applying slurry to the wax pattern

5. Hair spray was applied to the wax pattern to increase slurry adhesion. Alternating layers of slurry and fine zircon sand to build up the first 2 shell layers for a detailed surface finish. Fused silica sand replaced zircon sand for the last 7 layers providing structure to the shell.

Figure 22 Shaking Zircon Sand onto the wax pattern

Figure 23 Applying slurry on complicated sections using a syringe

Figure 24 First couple layers of coatings

Figure 25 Final layer of "Shell" mold

6. The shell went into the UW-Platteville made ‘Ring of Fire’ to burn out the wax sequentially from the bottom to the top. The goal is melting out small portions of the wax providing an outlet while preventing shell cracking.

Figure 26 'Ring of Fire' Burnout in action

7. With this being the longest dimensional investment casting poured in-house at UW-Platteville; an enlarged furnace was made to pre-heat the shell to 2,000°F. The pre-heated shell was placed on a modified cart so when the metal was poured in the pouring basin as in Figure 28, the shell could be lifted to a vertical position, filling the rest of the mold (see Figure 29). The Modified 5160 steel was poured at 2,950°F. This modified tilt-pour process was necessary because the length of the sword was impossible to pour at our facility if started in the vertical position.

Figure 27 Shell Pre-heat furnace in action

Figure 28 Modified 5160 Steel Poured

Figure 29 Shell mold tilted to the 'vertical' position

Heat Treatment

1. Heat treatment consisted of an austenitizing temperature of 1,525°F and quenched in soybean oil for 9 seconds. The blade was tempered twice, the first time at 375°F for 45 minutes and the second temper at 375°F for 1 hour 15 minutes. Figures 32 and 33 show the tempering furnace made to fit the dimensions of our sword.

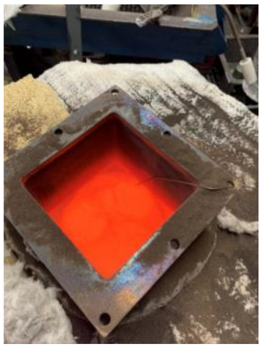


Figure 30 Argon fluidized Heat Treatment Furnace

Figure 31 Sword being quenched in soybean oil

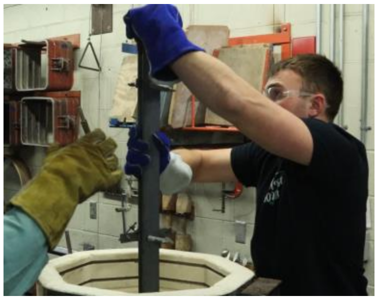


Figure 32 Inserting the blade in the tempering furnace

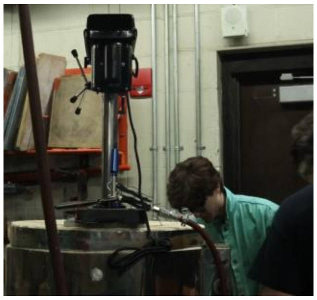


Figure 33 Covering the tempering furnace with a fan blade to distribute uniform heat

Handle

Design

When our team was deciding on what sword we wanted to replicate for this competition, the handle geometry was the major deciding factor. We wanted to cast the handle as one piece, avoiding extra fit and finish work that could prove devastating in testing if not done properly. The Broadsword was the only handle we were comfortable with being able to recreate as a one-piece casting. To match the historical significance of the original brass hilt, we used C87850 brass to cast our hilt.

Our interpretation of how the hilt was made back in 1795 was that all the brass other than the guard was a thin sheet formed around a leather-wrapped wooden handle. Though we wanted to push the boundaries with casting thin steel, casting brass sheet was not an option for us. Keeping all external features identical to the original, we remodeled the hilt to have a majority of the handle be cast brass, with a core for the tang and room for scales and a leather-wrap. This design can be seen in Figure 34. This design hardly had room for error. Keeping our tang as large as possible will yield us the highest probability that we do not have a catastrophic failure at the tang-bolster interface, which is constraint number one. Constraint number two was the minimum wall thickness of the brass handle. A wall thinner than 0.130” would not feed thicker sections of the hilt. Already, this design is nearing 0.500” wide. A comfortable handle in the hands of the judges should be around 0.625” thick, leaving us no room for error if we intended to wrap the handle with 0.0625" thick leather.

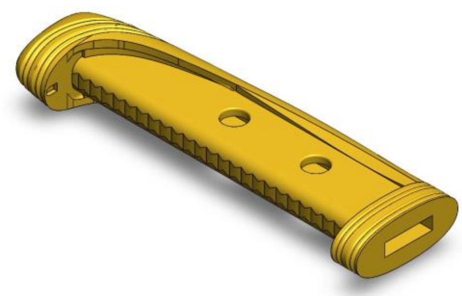


Figure 34 SolidWorks model of the handle

A SolidWorks assembly of the hilt gating can be seen in Figure 35. The core required for this process was proving to be difficult. It wasn’t until the 2025 Wisconsin Regional Conference that we thought about the idea of a 3D-printed sand mold after talking to Matthews Additive Technologies. This molding method would eliminate a lot of the troubles we were experiencing with the core and draft on the casting. We obtained three 3D-printed molds from Matthews, cleaned them out, assembled them and all three castings came out great.

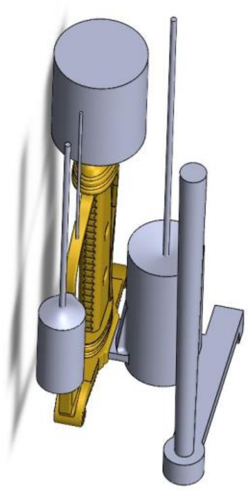


Figure 35 SolidWorks assembly of the hilt gating used in 3D-printed molds

Casting

1. Designing gating to produce a sound casting while being historically accurate were the top priorities. The gating and pattern design was simulated using MAGMA Software. Figure 37 shows a small spot for potential porosity at a low enough percentage to be considered negligible.

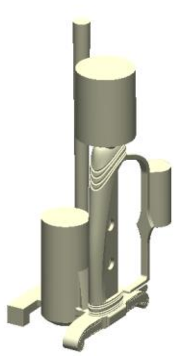


Figure 36 CAD Model of Hilt Gating

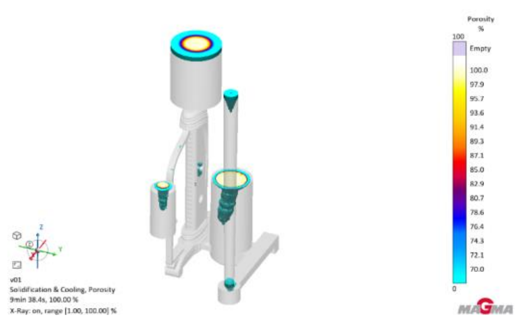
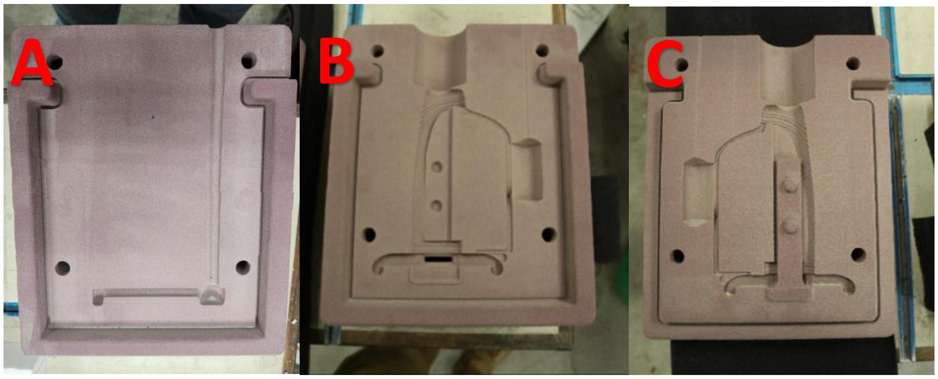


Figure 37 Computer Simulation of Gating Porosity

2. The design was sent out to be made using 3D printed sand molds. A parting line down the middle of the blade was chosen to allow all uncured sand from the 3D sand printing process to be removed.



Figures 38 The mold containing the sprue (A), mold with the ingate (B), and the final mold containing the core (C)

3. 3D printed sand molds were cleaned and assembled for pouring. Figure 40 was poured at 1,975°F and produced a sound casting with no defects.

Figure 39 Pouring the C87850 Ecobrass

Figure 40 First hilt casting

4. The casting was degated (Figure 41) and machined to final dimensions (Figure 42).

Figure 41 Filing and removing gating from the casting

Figure 42 machining final dimensions into casting

5. Finishing the hilt was the final and most time-consuming process. Figure 45 shows the final casting. The details on the hilt were laser-engraved into the casting combining historical accuracy and modern technology.

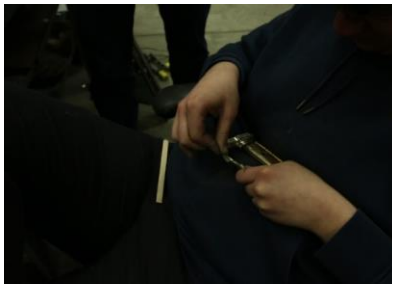


Figure 43 Hilt being polished

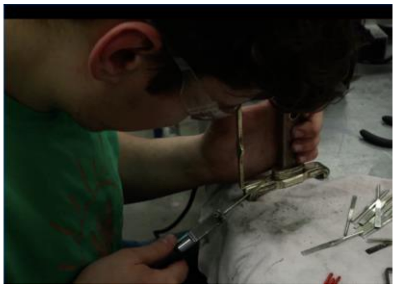


Figure 44 Filing the hilt

Figure 45 Hilt engraving

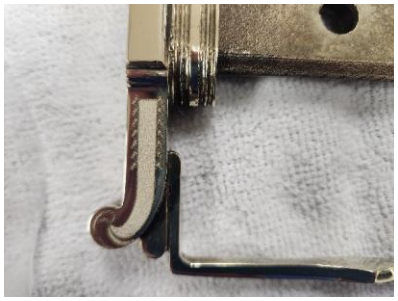


Figure 46 Polished hilt

Fitting

Processes of joining used throughout history include riveting or using a threaded pommel. An alternative method learned from previous Cast in Steel Competitions was a low-melting point bismuth based eutectic alloy to join them together.

An alloy that expands as it cools will be needed to fasten the hilt to the tang. A low-melting point alloy would be needed to not affect the temper of the sword. The alloy chosen is a Bismuth based eutectic alloy that has a melting point of 203°F and a growth of .005 inches per foot in 5 hours after casting (Belmont Metals).

Several tests were completed to test its behavior with steel. The best joint was achieved by heating both the steel and brass to 250°F. Preheating the hilt and sword prevents the chilling affect while also providing an infinite cooling time to set the sword and the hilt in the exact location it needs to be.

Wapping

The handle was designed to look as if it were wrapped all the way around with leather and held in place with braided wire, with both the leather and wire tucked behind the brass and along the spine of the handle. This effect was achieved by milling a groove at the edge of the polished spine, allowing the leather to sit flush rather than tuck underneath. The shape of the handle was formed using an FDM 3D-printed core, which went through multiple iterations to achieve a design that was both comfortable in the hand and true to the original. The leather was painted gold and engraved to mimic the appearance of a wire wrap. The leather was attached to the handle using contact adhesive, while the core was bonded to the brass with epoxy.

Figure 47 3D printed handle core

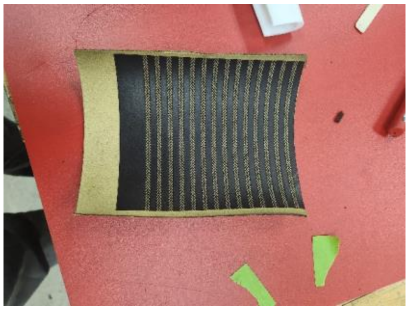


Figure 48 Engraved leather

Figure 49 Cut leather

Figure 50 Wrapped handle

Figure 51 Unattached handle

Figure 52 Epoxy

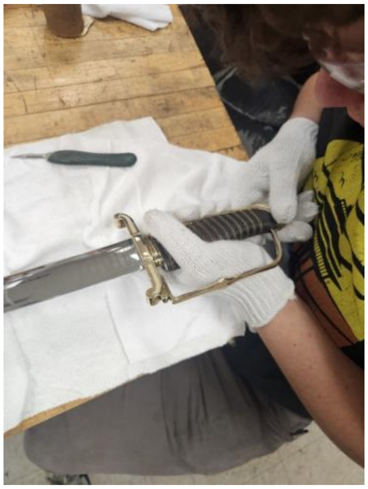


Figure 53 Final fitting

Figure 54 Glued handle and sword

Data/Results

Hardness

Hardness was obtained by slicing samples from the riser near the tip of the sword and are recorded in the Rockwell C scale. Two samples of varying thickness were ground to be representative of the major and minor thicknesses of the sword. For this project a hardness of 57-60 HRC was desired to achieve high toughness while maintaining cutting performance and edge retention. The oil quenched and tempered samples reached a hardness of 59.7HRC and 58.7HRC for the thin and thick sections respectively, seen in Figure 55. Factors affecting hardness include austenitizing temperature, cooling rate during quench, time and temperature of temper, alloying elements, carbon content, and grain size.

Commented [HW1]: Waiting for temper results

0.083" Sample	As Cast	Air Quench	Oil Quench	Oil Quench + Temper
Test 1	34	53	63	59.5
Test 2	35.5	55	62.5	60
Test 3	36	58.5	63	59.5
Average	35.2	55.5	62.8	59.7
0.156" Sample	As Cast	Air Quench	Oil Quench	Oil Quench + Temper
Test 1	36	50	62	58.5
Test 2	35.5	51.5	62	58.5
Test 3	41.5	49.5	63	59
Average	37.7	50.3	62.3	58.7

Figure 55 Riser Hardness Testing Results

Jominy Testing

The Jominy end quench test is used to determine the hardenability of steel. To perform a Jominy end quench test a one-inch diameter bar four inches long, Figure 56, is heated to austenitizing temperature. Next the bar is placed into a fixture that flows water onto one end of the bar quenching and cooling it at a variable rate in the vertical position. The water jet should have an unimpeded height of two and a half inches. After cooling completely in the fixture two flats are ground and hardness values are taken on the bar every 1/16th of an inch along its length starting at the quenched end (see Figure 57). The resulting hardness values are plotted, and a curve is produced (see Figure 58). The Jominy end quench curve is helpful when determining the cooling rate required to obtain a particular hardness with specific steel and can help when selecting quench media. The modified 5160 alloy used has higher hardness values at all points along the Jominy bar when compared to a standard 5160 alloy from literature. This indicated that the Chromium additions were successful in increasing the hardenability of the steel.

Figure 56 Quenched Jominy test bar

Figure 57 Jominy Bar after hardness testing

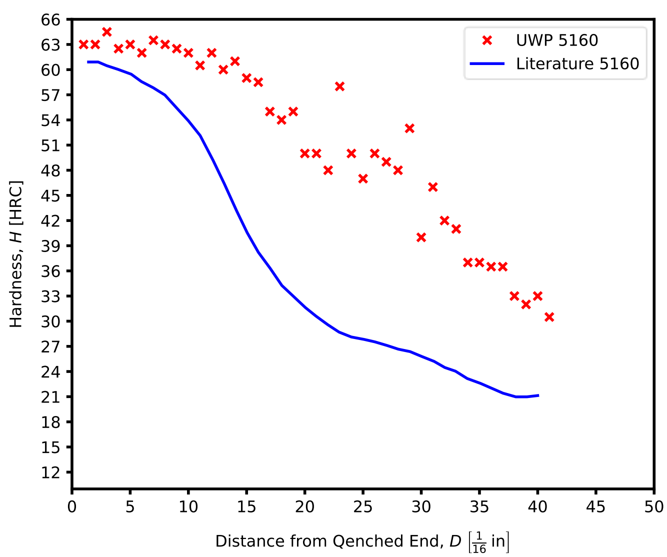


Figure 58 Jominy end quench curve of 5160 and UWP modified 5160

Charpy V-Notch

Charpy V-Notch samples were cast from the same heat as the submitted swords. They were machined in accordance with ASTM E23 and broached. The samples were put through the same heat treatment recipe as the sword and tested on a Tinius Olsen Charpy V-Notch tester. The average of the samples tested measured 16 foot pounds. Comparing this data with a normalized sample of 5160 from MatWeb in Figure 61, it can be seen that the impact strength nearly doubled with the heat treatment recipe used. Figure 58 shows that the hardenability of the 5160 alloy poured for this project was significantly greater than hardenability of literature 5160. A quick verification of the heat treatment process can be looking at the grain size of the fracture. Looking at the fracture in Figure 60, a fine grain size can be observed, indicating a sound heat treatment process resulting in the least likely change for a crack to propagate through the matrix.

Figure 59 As cast Charpy V-Notch sample

Figure 60 Charpy V-notch sample post testing

AISI 5160 Steel, normalized 855°C (1570°F)

Categories: Metal; Ferrous Metal; Alloy Steel; AISI 5000 Series Steel; Low Alloy Steel; Carbon Steel; High Carbon Steel

Material Notes: Contains a medium-to-high level of carbon. It is directly hardenable to medium hardness. Used for applications with smallish cross sections in severe service, notably automotive leaf springs and other spring and fastener uses.

Key Words: SAE J770, UNS G51600, ASTM A322, ASTM A331, ASTM A505, ASTM A519, ASTM A519, SAE J404, SAE J412

Vendors: No vendors are listed for this material. Please click here if you are a supplier and would like information on how to add your listing to this material.

Printer friendly version Download as PDF Download to Excel (requires Excel and Windows)

Export data to your CAD/FEA program

Add to Folder: My Folder 0/0

Physical Properties	Metric	English	Comments
Density	7.85 g/cc	0.284 lb/in³	

Mechanical Properties	Metric	English	Comments
Hardness, Brinell	269	269	
Hardness, Knoop	294	294	Converted from Brinell
Hardness, Rockwell B	99	99	Converted from Brinell
Hardness, Rockwell C	27	27	Converted from Brinell
Hardness, Vickers	284	284	Converted from Brinell
Tensile Strength, Ultimate	958 MPa	139000 psi	
Tensile Strength, Yield	530 MPa	76900 psi	
Elongation at Break	17.5 %	17.5 %	in 50mm.
Modulus of Elasticity	205 GPa	29700 ksi	Typical for steel
Bulk Modulus	160 GPa	23200 ksi	Typical for steel
Poissons Ratio	0.29	0.29	Calculated
Machinability	55 %	55 %	spheroidized annealed and cold drawn. Based on 100% machinability for AISI 1212 steel.
Shear Modulus	80.0 GPa	11600 ksi	Typical for steels.
Izod Impact	11.0 J	8.11 ft-lb	

Figure 61 MatWeb data for normalized 5160 steel

Spectrometer

Our final sample, Figure 62, had Silicon, Manganese, and Phosphorus levels within the stated range of 5160 found on Matweb Figure . Chromium is above the specified amount as expected and Nickel addition is present in our testing. Exact Carbon content was tested by Carbon combustion analysis explained below.

Target Compositon	% C	% Si	% P	% Mn	% S	% Cr	% Ni	% Ti
	0.603	0.289	0.019	1.05	0.005	1.003	0.53	0.029
Sample 9-1 Composition	0.656	0.265	0.029	0.943	0.0039	1.021	0.545	0.037
Sample 9-2 Composition	0.651	0.267	0.018	0.963	0.0035	1.026	0.548	0.036

Figure 62 UWP modified 5160 Final Composition

Carbon Combustion Analysis-

Carbon combustion Analysis was conducted using the Bruker G4 Icarus Carbon Sulfur analyzer. The amount of Carbon and Sulfur within a sample is obtained by weighing a standard amount of the desired sample and combusting in an environment with excess oxygen. Carbon and Sulfur bonds with Oxygen to produce CO_2 and SO_2 Respectively. The amount of CO_2 and SO_2 is measured to determine the corresponding percentage of each element in the sample (Titan Metallurgy).

The final Carbon combustion analysis in Figure 63 labeled “Sample 8” indicated 0.601% Carbon and 0.0052% Sulfur. Comparing these to the target values of 0.603% Carbon and 0.0052% Sulfur shows we are within the tolerance of 5160 and our modified melt.

Carbon Sulfur Analysis	C	S
Target Composition	0.603	0.005
Sample 1	0.781	0.0042
Sample 2	0.777	0.0045
Sample 3	0.779	0.0065
Sample 4	0.759	0.0056
Sample 5	0.705	0.0055
Sample 6	0.674	0.0079
Sample 7	0.6	0.0053
Sample 8	0.601	0.0052

Figure 63 Carbon combustion analysis results

Microstructural Analysis

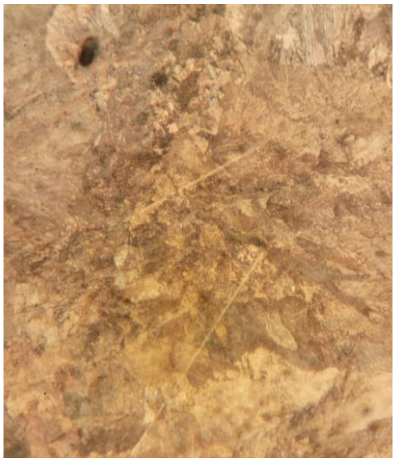


Figure 64 As cast structure 1000x magnification

Figure 65 Quench and temper structure 1000x magnification

The cast structure was anticipated to show a matrix of primary pearlite and ferrite. The final heat-treated microstructure was anticipated to show a matrix of tempered martensite. Tempered martensite is ideal for the physical properties that are needed in the blade.

In Figure 64 As cast structure 1000x magnification a primarily pearlitic structure can be seen with very little ferritic structures present. In the Figure 65 Quench and temper structure 1000x magnification a mostly martensitic structure with some ferrite is present. The primarily martensitic structure gives the blade great hardness while the ferritic structures allow for a good toughness and durability.

Conclusion

A near net casting was made on weight and size and successfully heat treated to yield a functional and aesthetically pleasing George Washington sword.

Mechanical, chemical, and metallurgical constraints were met as intended from results.

Never-before-seen size limits of in-house investment casting showed our creative innovation. Joining of the sword and hilt without effecting the heat treatment of the sword was achieved.

An Alte Presentation Broadsword showcasing the rich history of George Washington by using source materials and insight throughout the period. Features of the sword were produced with modern processes for the best historical accuracy.

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