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

Instituto Tecnologico de Saltillo – Blade Forgers

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SUMMARY

The SFSA Cast in Steel 2025 project, led by the *Blade Forgers* team from Instituto Tecnológico de Saltillo, aimed to design and cast a historically inspired sword paying tribute to George Washington. The project was inspired by two of Washington's historically significant swords: the Alte Presentation Broadsword, which influenced the hilt design, and the Silver Lion-Headed Cuttoe Sword, which inspired the blade. These swords symbolized Washington's leadership and were crafted with both aesthetic and functional elements in mind.

To manufacture the replica, the team employed the investment casting process, a technique well-suited for producing intricate and high-quality metal components. The process began with 3D modeling and printing, followed by the creation of silicone molds and wax models, which were then assembled into wax trees. The wax trees were coated with multiple layers of ceramic slurry, which hardened to form the casting mold. The wax was removed through dewaxing, and the ceramic molds were sintered at high temperatures to strengthen them for stainless steel casting. The pommel and guard were separately cast in bronze at an external foundry.

Throughout the project, the team faced several challenges, including thermal shock cracks, porosity caused by furnace contamination, and engraving defects resulting from imperfections in the 3D-printed model. Despite these obstacles, the final sword met the desired specifications, measuring 95 cm in length and weighing 1.5 kg. The team highlighted the importance of precise process control, especially in wax modeling, ceramic mold preparation, and alloy selection, to ensure a high-quality final product.

Ultimately, the project demonstrated the effectiveness of investment casting for creating complex reproductions while emphasizing the need for meticulous planning, quality control, and process optimization. The experience provided valuable insights that will benefit future industrial applications and improve efficiency in similar manufacturing projects.

CONTENT

I. INTRODUCTION

George Washington's swords were not only symbols of authority and leadership but also reflected the high level of craftsmanship and metallurgical technology of his time. Among the most well-known are the ivory-hilted sword and the steel sword with a gold hilt, both designed with a combination of functionality and elegance. These weapons were made from carbon steel alloys, forged and tempered to ensure their strength and flexibility in combat. The details on the hilts and guards often included materials such as brass, silver, and leather, enhancing their aesthetic and historical value.

Today, the manufacturing of replicas of these swords has benefited from the application of the *investment casting* process, a precision casting technique that allows for the exact reproduction of metallic components with a high level of detail. This method is widely used in the production of complex parts within the aerospace, automotive, and defense industries. Thanks to this process, it is possible to faithfully recreate the original designs of Washington's swords, ensuring that each replica maintains the same proportions, finishes, and mechanical properties as the originals.

Investment casting enables the production of components with tight tolerances and high-quality surface finishes, making it ideal for manufacturing guards, pommels, and other decorative elements of the swords. Additionally, by utilizing modern alloys, mechanical properties can be improved without compromising historical aesthetics. This combination of traditional techniques with advanced technology ensures that the legacy of George Washington's swords is preserved with the highest authenticity possible, allowing for their study, exhibition, and appreciation today.

II. ALTE PRESENTATION BROADSWORD

The single edged German hunting sword has a stirrup guard strap of gilt brass, the grip is made of leather wound and copper wire. The blade has a dedicatory legend in german which translates to: “DESTROYER OF DEPOTISM, PROTECTOR OF FREEDOM, STEADFAST MAN, TAKE FROM MY SON´S HAND THIS SWORD, I PRAY THEE, THEOPHILUS ALTE AT SOLINGEN”.

This german hunting sword was inherited to George Washington from Lawrence Washington, oldest brother and mentor of George Washington, he was a political leader and military, he served in campaigns like the Braddock campaign and the war against Native Americans, Lawrence died at a young age in 1752 due to illness. This sword has a lot of history. Alte’s son left the sword as a pledge at a tavern, and Lawrence wrote to John Quincy Adams, then U.S. Minister to the Netherlands, to inquire about the maker. Theophilus Alte was the swordsmith who made the sword, they know that because of the inscription on the sword, this inscription carries a symbolic message referring to ideals of freedom and resistance against tyranny. Solingen is a city in Germany famous for its tradition of producing high-quality swords, indicating the sword is German.

From Washington to John Quincy Adams: Your favour of the 11th of Feb: and a duplicate thereof, have been duly received; and I pray you to accept my best thanks for the trouble you have had in tracing to its origin, the history of the Sword which came to my hands last year, in the manner communicated in a former letter. As it is more than probable you will have left Holland before this letter can be received, I shall give you no further trouble in the affair than merely to inform you that I have never seen, or heard more of Alte than the account given of him in your letter of the above-mentioned date.

Figure 2. Altle Presentation Broadsword

III. THE SILVER LION HEADED CUTTOE SWORD

This short sword, acquired by Washington shortly before the outbreak of the American Revolution (1775–1783), reflects not only his personal taste and social status but also the cultural and military influences of the time. Today, it is part of the permanent collection at Mount Vernon, Washington's historic estate in Virginia.

This type of weapon was popular in the 18th century. The Silver Lion-Headed Cuttoe stands out for its silver hilt adorned with a lion's head pommel, a symbol of strength, courage, and nobility that was very common in British and European swords of the period. The inclusion of a lion's head in the design was not only decorative but also reflected the influence of European military traditions in the American colonies. The design and craftsmanship of the sword suggest that it was produced in Britain or at a European center specializing in high-quality weaponry. The silver used in the hilt and the intricate decorative details demonstrate the level of artistry and attention to detail, reinforcing the idea that this sword was intended both as a status symbol and as a functional weapon.

It is believed that Washington acquired this sword shortly before the start of the American Revolutionary War. Although there is no definitive evidence that he used it in combat, family tradition and historical documentation suggest that Washington carried this sword during the early years of the conflict. At that time, Washington was in the process of consolidating his military and political leadership, so the Silver Lion-Headed Cuttoe may have served as a symbolic tool to reinforce his image as a commander and statesman.

Beyond its functional value, the sword also served a representative purpose. Swords of this type were used by high-ranking officers in ceremonies and official events, where the presence of a finely decorated sword reflected power and authority. The lion's head, in particular, would have reinforced Washington's image as a strong and determined leader, capable of guiding the colonies toward independence

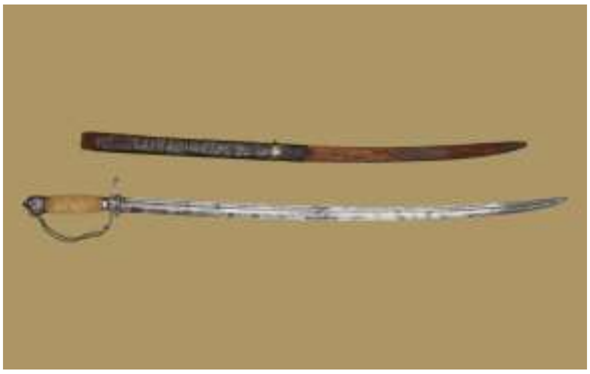

Figure 3. The Silver Lion Headed Cuttoe Sword

For the sword, the team designed and cast a sword centered around George Washington, inspiration was drawn from two historically significant swords: the Alte Presentation Broadsword for the hilt and the Silver Lion Headed Cuttoe Sword for the blade. The Alte Presentation Broadsword was selected as a reference for the hilt due to its intricate craftsmanship and a ceremonial significance, which reflects the prestige and honor associated with Washington's legacy. The detailed design conveys a sense of authority and leadership, qualities that Washington embodied throughout his life.

For the blade, inspiration was taken from the Silver Lion Headed Cuttoe Sword because of its elegant yet practical form. The refined shape and balance of this sword represent both strength and sophistication, characteristics that we wanted to incorporate into our final piece. By combining elements from these two swords, the objective was to create a unique and historically inspired weapon tribute to George Washington.

IV. DESIGN

The design was based on the Alte Presentation Broadsword and the Silver Lion Headed Cuttoe Sword, as previously mentioned. First, a freehand design was created, taking into account the specific requirements such as length and weight, as shown in Figure 1. Subsequently, the design was transferred to a 3D model using Autodesk Inventor software.

The selected design consists of three distinct components: the sword blade, the pommel, and the guard, which are intended to be assembled. The team agreed that both the pommel and the guard would be cast in bronze, while the blade would be made of steel. This decision was primarily made to ensure that the sword would not exceed the weight limit established for the competition. Furthermore, although the sword was intended to be a replica of the Alte Presentation Broadsword, the team decided to slightly modify the blade design, drawing inspiration from the Silver Lion Headed Cuttoe Sword. This change was motivated by the fact that the blade of the Alte Presentation Broadsword features numerous engravings, so the team opted to simplify the design specifically on the blade.

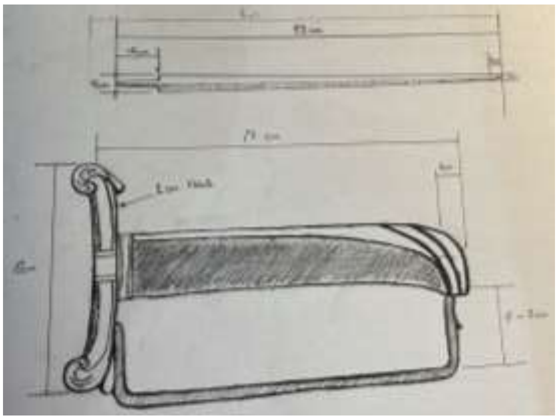

Figure 4. Initial Sketch

Figure 4.1. 3D Design

The team decided to use the investment casting process due to its ability to produce pieces with a high level of detail and complexity, ideal for components like the pommel and the guard. This process is particularly suitable for ornamental parts with complex shapes, as required in the design.

V. MANUFACTURING PROCESS

5.1 3D Printing

The first real challenges were addressed in the 3D printing, for the Rain-Guard and the Pommel, the decision was to print it in PLA (Polylactic Acid), the pommel was misaligned, as in the first photo it looks, it needed to be straightened, and decided to use a small amount of heat was applied to correct this. The Rain-Guard and Pommel were printed in another place (3Dreams Saltillo) because the printer at FAE company was not working, and decided to go to the other location due to time constraints. However, the issue with FAE’s printer was later resolved, and the printing of the blade was there.

Figure 5. 3D printing of pommel and guard

Since PLA does not provide the best surface finish, for the blade the decision was to print it out of PVC (Polyvinyl Chloride), rigid PVC has a smoother surface compared to PLA because of its lower tendency to warp and shrink during the cooling process, leading to more uniform layers and fewer visible print lines.

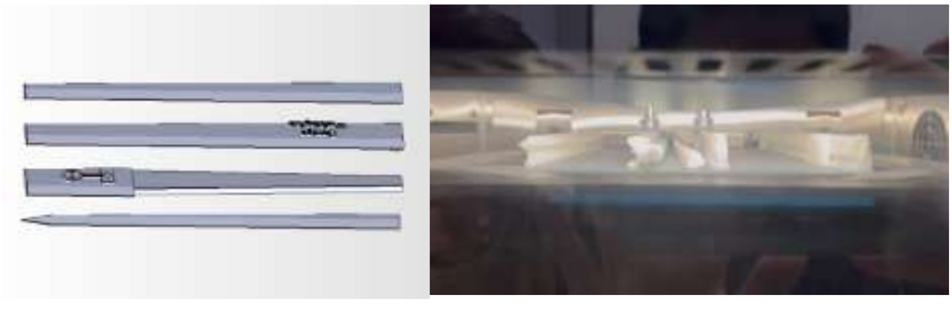

Figure 5.1. 3D printing of the sword blade in 4 parts

The blade for the 3D printing was divided in 4 segments, each one of 23.7 cm (9.35 in) because the height of the 3D printer did not allow to print the blade in a single piece. Subsequently the 3D printed sword was used to make the silicon molds.

5.2 Silicone Molds

Based on the previously printed 3D prototype of the components, the manufacturing process of the silicone molds was initiated. Initially, a 2-inch-wide plastiline base was constructed to stabilize the components during the molding process. Subsequently, plastiline walls were positioned around the base to create a containment barrier, ensuring greater mold consistency and preventing silicone leakage during the pouring phase. Additionally, embedded nuts were strategically incorporated to serve as alignment guides, facilitating precise mold closure, as illustrated in Part 1 of the figure.

Once the mold base was established, the silicone mixture was prepared according to a formulation ratio of 2 ml of catalyst and 20 ml of solvent per 100 g of silicone. The mixture was applied in two successive layers to ensure uniform coverage and eliminate potential defects. After the silicone had fully cured, a fiberglass and polyester resin composite was prepared, maintaining a ratio of 3 ml of catalyst to 200 ml of resin. This composite was applied over the cured silicone to form a structural shell, also known as a counter-mold, which enhances mold rigidity and stability, facilitating handling and the subsequent wax injection process.

For the fabrication of the mold counterpart, a release agent was applied to the silicone surface to prevent adhesion between the new and existing silicone layers. The molding process was then repeated following the same procedure. This process was systematically executed for all six previously printed 3D components.

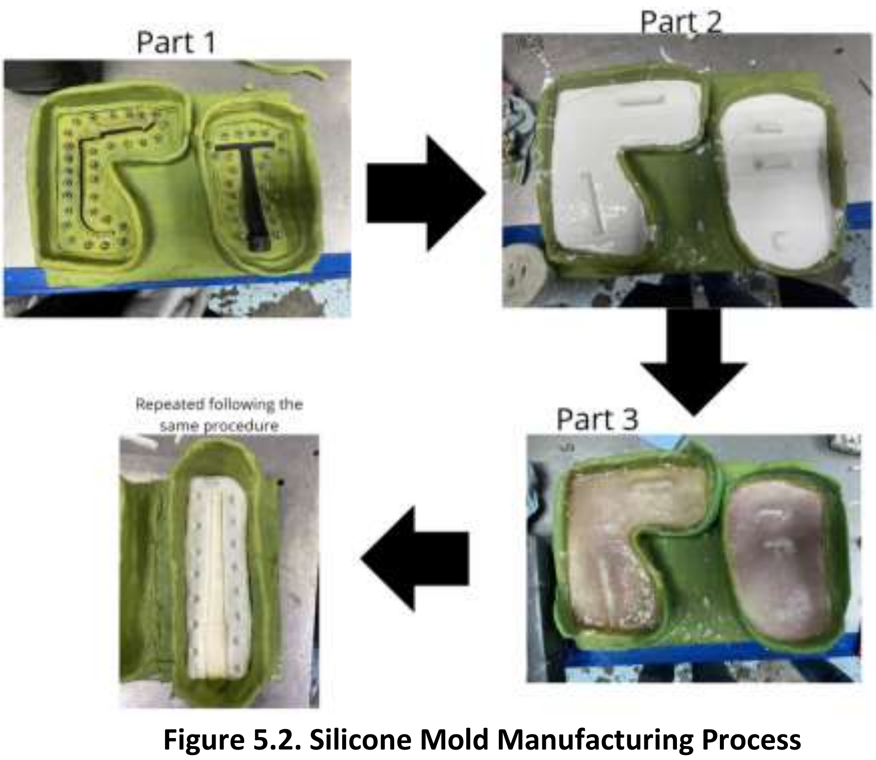

Figure 5.2. Silicone Mold Manufacturing Process

5.3 Wax modeling

In investment casting, wax is used to create a detailed model of the piece to be manufactured. Wax is one of the most important variables in this process. The foundation of the process is that the wax model is an exact copy of the desired metal piece. This natural wax has been used for centuries due to its excellent moldability, smooth surface finish, and ease of removal. The glass transition temperature of beeswax is 336 Kelvin, but to achieve good flow during pouring into silicone molds, the temperature was increased to a range of 523–623 Kelvin.

During the initial stage of the modeling process, the wax was poured into the pommel and guard molds, followed by the molds for the four blade sections. Finally, six wax models were obtained from each mold to assemble six swords. As expected, the wax models were not perfect, so they were reworked using moldable wax (candelilla and carnauba wax) and heat application with metal spatulas.

Figure 5.3. Wax Pieces for Casting Tree Assembly

The biggest challenge during the wax modeling stage was the fragility of the wax due to the width of the sword blade. Handling the wax blade without fracturing it was a significant issue. Due to the nature of the project, the swords broke multiple times.

5.4 Wax trees

For the fabrication of the wax tree, it was necessary to design a structure strong enough to withstand the handling of the tree and the weight of the ceramic slurry, considering the thinness of the blade. As a preventive measure, three tree designs were proposed to ensure that at least one would complete the process and be successfully cast. Some did not withstand the first stage of the slurry, while others managed to receive 3-4 layers of ceramic before eventually fracturing.

The first design used two blades joined by rectangular plates, which provided the geometry needed to accommodate the castings. Three castings were placed, each connected by a larger plate in between.

Figure 5.4. Assembled Wax Trees for Casting

The second proposed design used a wax post as a base, onto which the two blades were assembled, one half on each side. This design ensured sufficient strength for the mold to complete the process; however, it had a drawback—it required splitting the blade into two parts, meaning it would have to be welded together once the pieces were obtained. As a result, the blade's properties would be compromised.

Figure 5.4.1 Vertically Designed Wax Tree for Casting

Lastly, the third design was very similar to the first, except that the position of the blades was different. With this geometry, the blade of the sword would not bear the weight of the casting cups. At first glance, this appeared to be the best design, as the blade was not subjected to any stress, unlike in the first design.

From the first option, three models were created: one fractured during the second ceramic layer, another fractured at the fourth layer, and the last one, fortunately, completed the entire process. From the second design, only one model was produced; as previously mentioned, it was highly resistant and therefore successfully completed the process. Finally, two models were made from the third design, but surprisingly, neither was able to complete the process. Apparently, they did not meet the proper geometry and morphology required to withstand handling and the weight of the ceramic.

The design of the pommel and guard tree was not very complicated; it only required attaching the pieces to the wax post using spatulas and heat. Each tree contained two pommels and two guards.

Figure 5.4.2. Assembly of Pommel and Guard

5.5 Preparation of the Wax Tree for the Slurry Coating Process

After the wax tree was fully assembled with its respective patterns and risers, the preparation of the investment mold was carried out. The process began with two cleaning stages prior to the application of the ceramic coating:

Initially, the assembly was washed using a perchloroethylene solution to remove grease or impurities.
Subsequently, it was rinsed with water to eliminate any remaining cleaning agent and carefully dried using a compressed air gun.
This procedure ensured that the tree's surface was clean and free of contaminants, thus promoting proper adhesion of the ceramic layers during the investment process.

Slurry
It is used to immerse the wax tree, creating the layers that will eventually become the ceramic mold. This material provides the adhesion and thickness necessary to ensure that the mold is precise and has the appropriate strength.
First Layer: The wax tree is immersed in a ceramic slurry, followed by a dusting with 100 mesh zircon sand. This ceramic slurry act as type of slurry that provides a solid base for the successive layers.
Drying Time**:** This layer requires 2 hours to dry.

*Second Layer***:** The wax tree is immersed again in the ceramic slurry, followed by a dusting with 80 mesh silica sand. This layer improves the strength of the mold and contributes to its precision.
Drying Time: This layer also needs 2 hours of drying.

Third to Seventh Layers: This step is repeated for the next five layers, immersing the tree in the ceramic slurry and dusting it with silica sand. The amount of sand used for dusting in each layer is 50 mesh silica sand.
Drying Time: Each of these layers requires 2 hours of drying, except for the final layer.

Final Layer (Seal Layer): The last layer, known as the "seal" layer, is applied by immersing the tree in a ceramic slurry without additional sand dusting. This layer is essential for providing final stability and the definitive shape to the mold.
Drying Time: This layer requires an extended drying time of 12 hours due to its thickness and the need for complete drying to ensure the integrity of the mold.

It is important to note that during manufacturing, some of the assemblies of the ceramic tree turned out to be fragile when applying the ceramic layers, which caused some molds to break. Due to this vulnerability, it was necessary to modify the types of assembly and apply additional techniques to ensure the strength of the mold. This involved implementing more robust assembly methods to ensure that the ceramic mold could withstand the layer application process without suffering damage.

Figure 5.5. Wax Tree After Slurry Coating and Sand Layering

5.6 Dewaxing

Once the ceramic mold was fully formed and dried, the *dewaxing* process was carried out. This process involves the removal of wax from inside the mold, primarily using an autoclave that applies high-pressure steam. This method is effective as it melts and expels the wax without damaging the mold, while also allowing the wax to be recovered for reuse.

Additionally, the mold was subjected to controlled heating at approximately 150 °C in a specialized chamber, which facilitated the melting and complete drainage of any wax residues. Subsequently, the mold was preheated to a temperature above 800 °C to ensure the total elimination of any remaining wax and to enhance the mold's strength before the metal pouring stage.

Precise control of temperature and time during the *dewaxing* process was crucial to prevent mold cracking and to ensure it was in optimal condition for the casting process.

Figure 5.6. Dewaxing Process of the Ceramic Mold

5.7 Sintering and Casting

Sintering hardens the ceramic mold, ensuring it can withstand the high temperatures and mechanical stresses during the metal pouring process, also it eliminates residual moisture and organic binders, preventing defects such as cracks, gas formation or contamination in the final casting, a properly sintered mold resists thermal shock, reducing the risk of mold failure when molten steel is poured.

The sintering furnace was heated to 1020°C (1868°F) for two hours.

Figure 5.7. Removal of the Sintered Mold from the Furnace

After the two hours, the mold was taken out (figure 5.7.1) and it was placed on a metal support covered with sand to ensure that the ceramic mold remained stable and properly positioned during the pouring process.

Figure 5.7.1. Mold Secured on Metal Support Before Pouring

They were weighed 47 kilograms (103.62 pounds) of SS420 Grade AISI 420 stainless steel, this steel is a straight chromium martensitic stainless-steel grade with certain wear resistance, corrosion resistance and high hardness.

VI. CHEMICAL COMPOSITION

	Chemical Composition, %								
ASTM	AISI (UNS)	C, ≥	Si, ≤	Mn, ≤	P, ≤	S, ≤	Cr	Ni, ≤	Mo, ≤
ASTM A240/A240M	SS 420 (UNS	0.15	1.00	1.00	0.040	0.030	12.0-14.0	0.75	0.50

Despite its high hardness and good properties, FAE company typically melts a 50% chromium-50% nickel alloy. Before the casting, the furnace had not undergone a cleaning process, as their usual method of cleaning involves steel. Consequently, the furnace was, in a way, "contaminated" with their nickel-chromium alloy, which affected the mechanical properties of the sword due to the high nickel content.

An excess of nickel in AISI 420 Stainless Steel significantly alter mechanical properties because AISI 420 relies on a high carbon content and low nickel content to achieve high hardness (typically 48-52 HRC) through the formation of martensite during heat treatment, nickel is an austenite stabilizer, an excess amount resulted in a softer structure and lowe overall hardness, also higher amount of nickel reduces the material ability to withstand abrasion and cutting forces.

Steel was melted at 1600°C (2912°F), poured into the sintered ceramic mold for 9 seconds at constant speed and left to cool for one day.

Figure 6. Casting Process: Steel Pouring at 1600°C

The second mold that was made was also poured, but since the blade was divided into two parts, welding the blade was not a viable option due to potential fragility. Therefore, the full blade mold was the most viable option.

6.1 Pommel and Rain-Guard

They were cast in bronze at another foundry that the FAE arranged for us, and the ceramic molds were already prepared and sent by them. However, there is not much information available about the process.

VII. SURFACE FINISH

7.1 Blade

Once the sword blade was obtained, the excess material from the casting process and the oxide layer produced by the previous heat treatment were removed using an angle grinder equipped with an abrasive disc. After the initial cleaning, various surface defects such as cracks and porosities were identified. These defects were corrected through a stainless steel welding process to ensure the structural integrity of the blade.

Figure 7 a) initial Surface Cleaning of the Sword Blade b) welding Process to Correct Casting Defects

Subsequently, a polishing process was performed using a rotary polisher with a wool pad and fine abrasive compound to achieve a uniform and high-quality surface finish. However, due to the hardness acquired from the heat treatment, the polishing process presented some challenges, requiring adjustments in the machine's speed and pressure to prevent surface damage.

Additionally, the lower part of the blade was ground down to ensure a precise fit with the guard. This operation was performed using a bench grinder equipped with a stone disc, ensuring accurate geometry and optimal assembly. Finally, a double-sided sharpening process was carried out on the blade edges using a belt sharpener to guarantee effective and consistent cutting performance.

7.2 Pommel and Guard

Since the pommel and guard were manufactured through bronze casting, the surface finish was improved using a shot blasting process with fine metallic particles. The shot blasting was conducted for approximately 5 minutes, achieving a homogeneous surface and a uniform texture that enhances the adhesion of any subsequent surface treatment, such as patination or polishing.

This surface finishing process resulted in components with improved wear resistance and an enhanced aesthetic appearance while maintaining dimensional tolerances and a precise fit with the sword blade

Figure 7.2 Shot Blasting Process on Pommel and Guard

VIII. FINAL ASSEMBLY

Once the desired surface quality was achieved on the three individual pieces, the assembly process was carried out meticulously to ensure the sword's structural solidity and stability.

The first step involved welding the blade to the guard, ensuring a strong joint through a carefully controlled welding process to prevent deformations and guarantee the proper alignment of the components. Special attention was given to cleaning the contact surfaces and selecting the most suitable welding technique, ensuring a homogeneous fusion of the material without compromising the mechanical integrity of the piece.

Subsequently, the attachment of the pommel, the third fundamental component of the sword's structure, was carried out. This element was joined to the tang of the blade through an additional welding process, optimizing strength and load distribution to prevent structural failures during prolonged use. Visual inspections and preliminary tests were conducted to verify alignment and welding quality, ensuring a strong and durable connection.

To complete the assembly, the sword's handle was integrated, which was crafted from oak wood due to its excellent mechanical properties, such as high impact resistance, durability, and dimensional stability. The handle was carefully carved and adjusted to ensure a precise fit with the tang and pommel, providing optimal ergonomics for the user

Figure 8. Fully Assembled George Washington Tribute Sword

IX. DEFECTS PRESENT IN THE PROCESS AND FINAL PIECE

- **Thermal Shock Cracks:** Cracks were identified in the material, possibly resulting from the high pouring temperature (**1650 °C**), which generated excessive thermal stresses in the mold.

- **Porosity Due to Furnace Contamination:** The presence of pores in the cast piece was observed, which could be related to possible furnace contamination. This contamination may have been caused by residues from a previous nickel-chromium alloy pour that remained adhered to the furnace walls, thereby affecting the quality of the casting.

- **Poor Letter Engraving:** A defective engraving of the letters on the piece was observed, likely caused by an inadequate 3D printing of the original model, which resulted in irregularities in the ceramic mold.

Figure 9. Defects Identified in the Casting Process

X. CONCLUSION

I. **Reproduction of Morphology and Defects**
The investment casting process allows for the precise reproduction of any morphology present in the wax model, including defects that may be present in it, with high fidelity. Due to this characteristic, the quality of the wax model is a determining factor in the structural integrity and aesthetics of the final product. Improper handling of the wax model, as well as a lack of experience in its manufacturing and handling, can directly compromise the quality of the final part, affecting its mechanical properties and surface finishes.

II. **Factors Influencing the Final Finish**
The final finish of the part obtained through investment casting does not depend solely on the wax model but also on key factors such as the ceramic process, sintering, and casting conditions. Additionally, the temperature and sintering time must be strictly controlled to ensure the mechanical stability of the ceramic mold. The pouring temperature is also a critical parameter, as inappropriate values can cause defects such as cracks, oxide inclusions, or material segregation. Another relevant aspect is contamination in the furnace, which can alter the properties of the alloy, reducing its hardness and strength, compromising the functionality of the final component.

III. **Process Restrictions and Planning**
The production of the sword was influenced by various logistical factors that impacted the efficiency and execution times of the project. The company's internal scheduling presented restrictions that made it difficult to coordinate between those responsible for each stage of the process. The difficulty in aligning schedules with those in charge of the different phases of investment casting caused significant delays, affecting the continuity of the production process.

IV. **Importance of Assembling the Sprue Tree**
The design and assembly of the sprue tree play a fundamental role in the resistance or fragility of the ceramic structure. It was concluded that improper distribution of the parts in the sprue tree can compromise the stability of the ceramic coating, affecting its integrity and increasing the risk of fractures during the process. A poor sprue tree configuration can generate stresses that weaken the structure of the ceramic mold, causing defects in the final part. It is essential that the sprue tree assembly be optimized to reduce these risks and ensure the uniformity of the ceramic coating.

V. **Properties and Dimensions of the Final Sword**
The final result of the process produced a sword weighing 1.5 kg and measuring 95 cm

in length, values that fall within the expected parameters for this type of component.

VI. Evaluation of the Work Done

Despite the technical and logistical challenges, the work was of high quality, considering the complexity of casting a sword nearly one meter in length using the investment casting method. Furthermore, the team gained valuable knowledge about the critical factors of this manufacturing process, which will help optimize future industrial applications and improve efficiency in similar projects. The experience highlights the importance of process control and proper resource management to achieve optimal results in the manufacture of high-precision components.