SFSA Cast In Steel 2025 - Washington's Sword

Technical Report

Cal Poly Pomona - The Crucible Crew

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Executive Summary

For the 2024-2025 SFSA Cast in Steel competition, our project execution was structured into distinct phases encompassing research, design, manufacturing, and processing, specifically for our sword production. We opted to go with a 4130 Carbon Steel as it was the best Carbon Steel provided by our foundry partner, Soundcast Co. was deemed optimal due to its heat treatability, enabling it to achieve properties akin to medium-high carbon steel. This characteristic would afford our sword superior impact and abrasion resistance, coupled with a favorable strength-to-weight ratio, ensuring durability and minimizing potential failure compared to swords crafted from alternative steels.

The casting process selected by our group was resin sand casting using a 3-D binder jet sand printer to produce our mold because of its high dimensional accuracy & ability to create complex geometries as opposed to investment casting. Green sand casting was another option that allows us to do unlimited geometries, but would not present us with the dimensional accuracy that such a sword from the 18th century would hold so we did not select green sand casting. The casting process steps used to create our sword incorporated the design phase allowing us to create our part using computer aided design (CAD) software which would allow us to create the proper design within project parameters and molding needed to produce our cope and drag for the casting process. Along with this, simulation of the gating system was used in order to ensure that the casting process would go as smooth as possible with as little shrinkage along the system as possible such that the casting will proceed without any imperfections or defects to the sword. After this, we had our printed molds arrive at the foundry to begin pouring in order to create our sword.

Upon the casting of our sword, the sword underwent rigorous inspection using optical emission spectrometry to verify that the elemental composition and material properties conformed to our defined upper and lower specification limits. Further processing was undertaken to reduce excess weight, ensuring compliance with the project's 4.4lbs weight

parameter. Prior to shipment and submission to the SFSA for the project presentation at the conference in Atlanta, GA, the sword was subjected to fundamental impact and abrasion tests.

Introduction

2a) Project Objective

The purpose of the SFSA Cast in Steel competition is to encourage students to learn about making steel products using available casting processes and applying the latest technology available. This year's competition aims to design and manufacture a George Washington sword. Students must document the project in a technical report, create a project video, and manufacture a steel casting of the sword. The team will be advised by a university faculty sponsor, and work with an industrial partner familiar with steel castings.

2b) Historical Context

During the beginnings of the United States, the sword a man would bear was important to his appearance and presentation. Swords would act as more than a weapon; they would conform to fashion as well. George Washington owned various swords throughout his life, each serving a different purpose. Washington would take the appropriate sword with him depending on the situation, one may be suitable for a battle while another would lend itself to a diplomatic meeting. The swords that he owned kept up to date with the latest fashions in Britain, with delicate details covering the hilts. Each of his swords were structurally similar but differed greatly in visual and detail. The 1753 Silver Hilted Smallsword that was chosen as inspiration for this project was carried by Washington during the French & Indian War. Our sword accurately reflects the core attributes of this historical weapon, featuring a strong, functional blade and an elegant design that aligns with the styles prevalent during Washington's time, thus making it an authentic representation.

2c) Physical Constraints

The sword will weigh no more than 2 kg (4.4 lbs.) The sword will be no longer than 1 m (40 inches) in overall length.

Research Phase

3a) Sword Composition

To begin our research, we looked at the components and parts that make up a sword, especially swords that would be more commonly used in the 18th century around the time of Washington's presidency and lifetime. We found that many blades consist of two primary components, the blade and the hilt. The blade is the portion of the sword designed for being sharp and able to cut or chop any materials or surface it encounters. The blade is made up of several sections that include the Point, Central Ridge, Edge, Fuller, and Ricasso.

To understand each section of the blade, we need to break down what they entail. The point of the sword is the tip of the metal blade. The central ridge is the portion of the blade that has a line running right through the middle. The edge of the blade is the sharpest portion of the blade. The fuller is the groove that goes through the center of the sword, reducing the overall weight and improving the flex and strength. The final portion of the blade is the riccasso, which is the unsharpened portion of the blade that is just above the guard portion of the hilt allowing for the person wielding the sword to take grip of the sword or wrap a finger around the blade for stability.

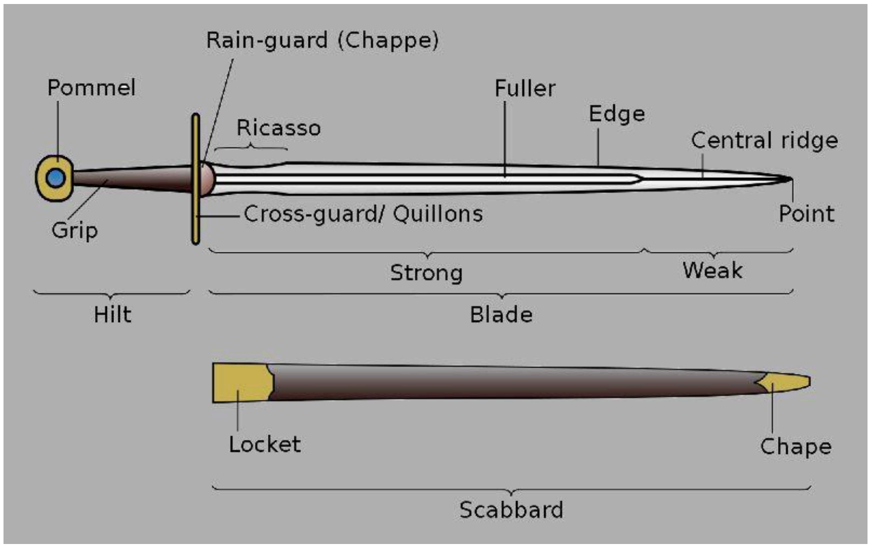

Figure 1: The composition of the sword with the parts listed across the blade and handle.

The next component of the sword that exists is the hilt, which is made up of the pommel, tang, rain, cross-guard, and handle/grip at its core sections. The pommel is a very important section of the hilt as it is the portion that connects the hilt to the blade and ensures they are secured together. The tang is a portion of the blade that runs through the interior of the grip/handle, which is then connected or secured to the pommel. The tang is the grip that is placed around to have a stable and safe grip for the user. The guard then serves as a barrier between the blade and the hilt to ensure the user doesn't accidentally cut themselves. There is also the chappe that resides in the middle of the cross-guard which is also referred to as the rain guard which serves to protect the blade from having rain seep into the cross guard or tang. The handle/grip acts as a resource for the user to be able to wield the blade and is usually made from a wooden finish/material or an extension of an alloy separate from the blade that allows the user to safely wield the sword.

3b) Material Research

Given that the project is Cast in Steel and one of the requirements is that a Steel alloy is what is cast, we immediately began researching for what type of steel would be the most ideal for the construction of a sword. We wanted to find a material that is optimal for casting and a material that is treatable to give us all the qualities of a sword that make it stand out such as good strength, good durability, sharpness, and impact resistance. When it comes to sword making, there will need to be subsequent treatment and procedures that are done in order to give the sword the qualities we are looking for.

Upon researching more about the different steels, we found that Carbon Steels are among the most popular steel materials that are cast in sword-making due to their versatility and wide range of applications along with its ability to easily be heat treated. Specific to swords we found that medium to high carbon steels ranging from a Carbon content of 0.3%-1.7% are used often in manufacturing swords due to their ability to remain sharp on the edges, endure a lot of wear or damage, and having excellent tensile strength and durability. Carbon steels; however, can be subjected to corrosion. In order to prevent corrosion, other elements are alloyed with the carbon steel such as nickel, chromium, or molybdenum to prevent corrosion while also retaining toughness and strength at elevated temperatures. Low or mild carbon steels would not be ideal for our sword given that they are far more ductile than medium-high carbon steels and also have a lower tensile strength relative to medium-high carbon steels. There also exist high-tensile steels that alloy specifically with Molybdenum and Carbon that allows for increased strength that going off SAE designations would reside in the 41xx family of Carbon Steels. [3] 41xx steels have incredible strength-to-weight ratios and are stronger than standard carbon steels. [4] This information surrounding 41xx steels will foreshadow our eventual material selection of 4130 carbon steel upon speaking with our foundry partner, Soundcast Co.

Physical Properties 4130		
	Annealed	**Normalized**
Density	0.283 lb/in3	0.283 lb/in3
Ultimate Tensile Strength	81.2 ksi	97.2 ksi
Yield Tensile Strength	66.7 ksi	63.1 ksi
Shear Strength	49 ksi	62 ksi
Hardness Rockwell | Brinell	B82 | 156	B92 | 197
Elongation at Break Percentage	28.2%	25.5%
Modulus of Elasticity	29,700 ksi	29,700 ksi psi
Reduction of Area Percentage	56%	60%
Melting Point	2,590-2,660 °F	2,590-2,660 °F
Specific Heat	1.14 x 10^-1 BTU/lb-°F	1.14 x 10^-1 BTU/lb-°F
Thermal Conductivity	296 BTU-in/hr-ft^2-°F	296 BTU-in/hr-ft^2-°F

Figure 2: Steel 4130 Physical Properties

Looking at 4130 as a metal, it has just enough carbon content to not be considered a mild steel which can range from 0.16% to 0.29% carbon content as well as treatment of 4130 medium carbon steel can give us the desired properties that a high carbon steel would give to a sword just with a bit more finishing. Plain carbon steels can also be much more brittle leading to possible cracks or fractures, so incorporating procedures like tempering and normalizing will make the metal more flexible and allow the material to be more ductile and less brittle in the process leading to a lower probability of failure by the sword. The material will also need to be normalized and quenched prior to tempering to ensure we get our desired strength and hardness properties so that when we temper, we can still get our desired properties in those categories [1].

Design Phase

4a) Design #1

The first design was a recreation of George Washington's 1753 Silver Hilted Smallsword. [2] The blade and handle are cast separately and assembled by fixing the handle onto the tang. A wooden grip is then slid over the tang. The tang is tapped to allow the pommel to be screwed into it. After a review with our partnered foundry, Soundcast, the design was found to be infeasible for sand casting due to its thinness, small dimensions, and low weight. The overall length of the first design was 37.12 inches with a small cross-sectional thickness measured from the base of 0.2 inches. This iteration did not utilize the maximum weight allowed for the sword as it only weighed 3.49 pounds when there is a maximum allowance of 4.4lbs. The long length and thinness of Design #1's sword would lead to cold shuts if cast. The second iteration of this design added thickness to the blade and handle. For a sword of this thickness, it was advised to add to the overall thickness of the sword ranging in an additional length and thickness of around 30%-40% from the original design to account for the lack of size present on the sword.

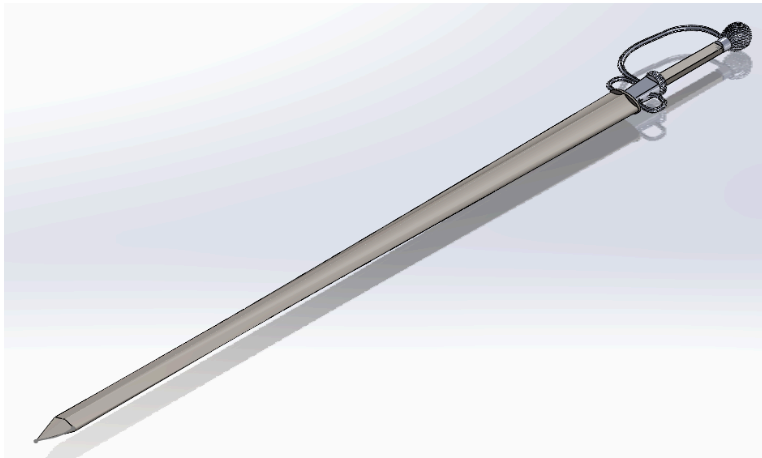

Figure 3: Sword Design #1 CAD model

4b) Design #2

The second design was an original design focused on avoiding the shortcomings of the first design, addressing the weight and thinness concerns put forward by our Foundry partner. A goal for this design was to reach near the maximum weight for the project to allow for an easier casting process, where the weight of casting was 4.52 lbs in solidworks. This weight is above the maximum requirement but some of this weight will be lost when grinding the sword for sharpening. The new overall length is slightly greater than the previous design at 38.38 inches. Swords of this historical period can come with or without a knuckle guard but when they do, the knuckle guard is quite thin and decorative leading to a difficult sand casting, so the design proceeded without a knuckle guard.

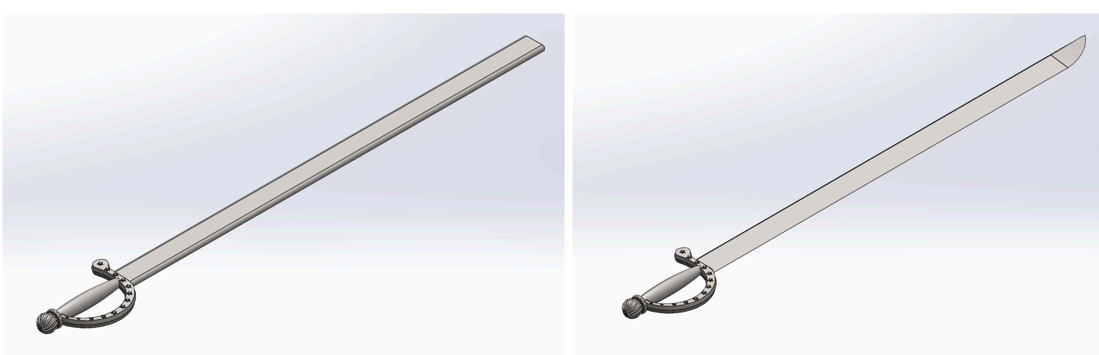

Figure 4: As Cast (Left) Sharpened (Right)

Another point of concern when casting was the connection of the handle to the blade, which as the thinnest part of the blade would be a high stress area, so the handle was made thicker at 0.4 inches.The handle and blade is cast together which despite the historical inaccuracy of this step, was essential to ensure the sword would be put together as best as possible without possible separation of blade from handle. Casting the blade and handle separately was avoided and everything was cast as one part and the grip is wrapped in tape for improved comfort and handling. In the end we proceeded with Design #2.

4c) Gating System

Once our design was approved by our point-of-contact at SoundCast, we immediately got to work rigging the gating system using SolidWorks and SolidCast to not only assemble our sword's gating system but also be able to run naked simulations without risers and runs along with the risers attached for our simulations thereafter. We went with a support bar attached to the bottom of our sword in order to prevent curling and a runner bar that would bottom fill from the support bar. Given that there is a lot of excess metal being used and that our Gating system is intended for one to two swords, the solution presented is low yield as it inhibits more production and profitability because it's a finite number of swords and not an infinite production rate with a large batch size. Within our simulation software, SolidCast, we wanted to make sure all our parameters were correct when running our simulation from the number of nodes being 10 million with risers included or down to the mold thickness itself which would be 4 inches. Our first risers were all evenly spaced out and incorporated a rectangular design. They would go up a quarter inch from the blade then expand out using the loft tool on SolidWorks to create a larger cross-sectional area to hold more reserve metal. The riser is extended up an additional inch from the base quarter inch mentioned prior.

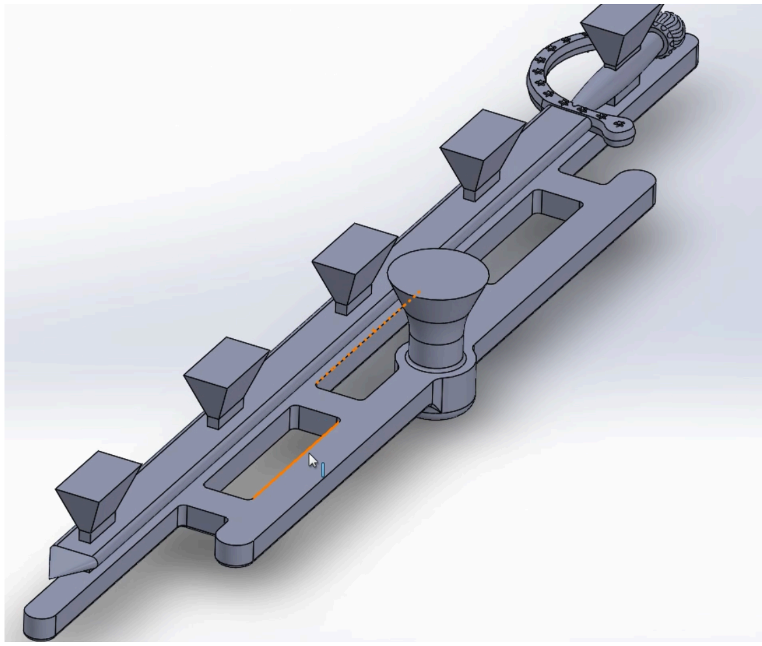

Figure 5: Sword with riser and gating system

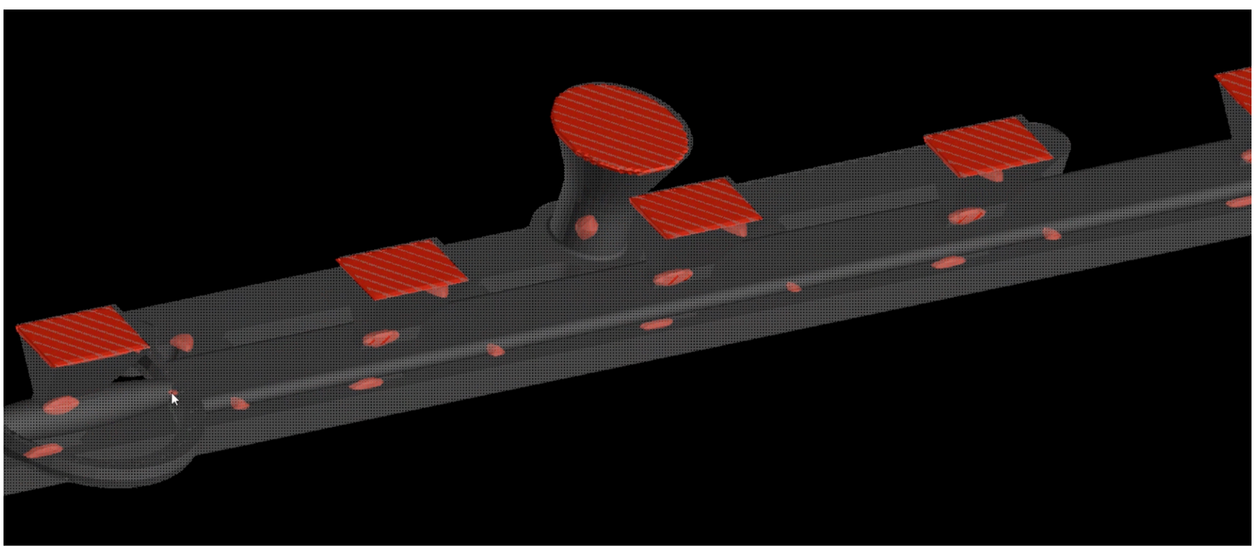

Figure 6: SolidCast Simulation

Upon running our first simulation with our gating, we found shrinkage to be present on the connections of the Riser and Blade as well as on the cross guard which connects our blade and handle. To counteract the shrinkage on the blade connected to the risers, we adjusted our lofted risers to be cylindrical risers that would present us with more overall surface area for metal reserves and also provide us with a 30% efficiency increase and allow us to add exothermic sleeves, which will control the rate at which the molten metal inside the risers freeze and ensure the risers are the last to solidify so that we can get a smooth supply of metal to shrinkage locations. For our cylindrical risers, we extruded about 1.25 inches in height, with a diameter of 1.59 inches, with 5 total risers to start to ensure minimal shrinkage occurs. Upon the simulation completing, we found that a lot of the shrinkage that existed between the riser and blade was no longer present and we now only had shrinkage existing on the cross guard portion of our sword which is a major problem if left unattended, allowing stresses to form and potentially leading to a premature failure of our sword.

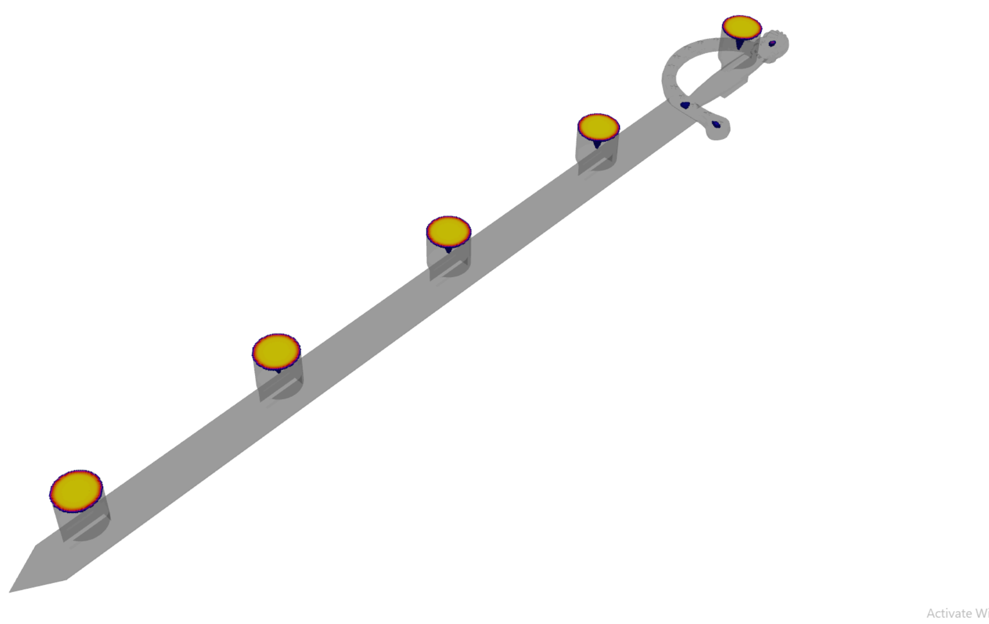

Figure 7: SolidCast Density Simulation without Risers

To counteract this we tested several riser additions along the ricasso portion of our blade and determined if we could eliminate the shrinkage there as it was the only significant shrinkage left along with minor shrinkage on our star design of the cross guard to the left and shrinkage present on the pommel of our sword. We tested risers that were both smaller and larger than our already pre-existing risers and found that a larger riser would eliminate the major shrinkage present on the cross-guard and upon simulation with the runner bar and support bars present were able to successfully remove that shrinkage upon completion of our simulation.

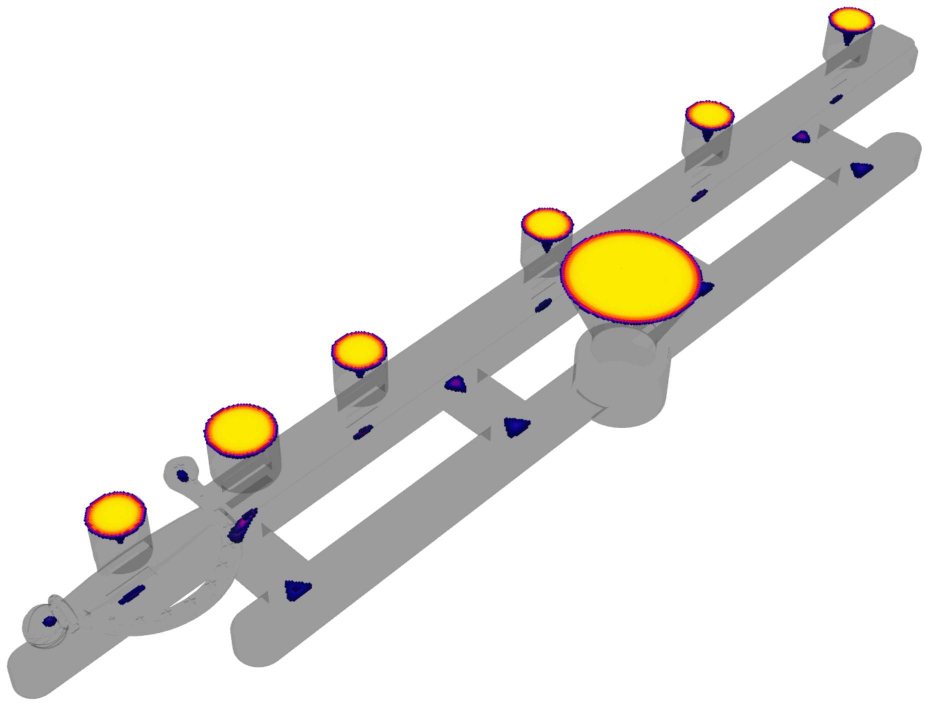

Figure 8: SolidCast Density Simulation with Gating

Production Phase

5a) Foundry Overview

Upon speaking with our advisor, it was determined that we would be working with Soundcast Co. which has a diverse portfolio of work with parts and products serving industries ranging from oil/gas, water and power, and city. Upon meeting with Soundcast via Microsoft Teams, we learned that they are a company that primarily pours stainless steels with low carbon contents and that they do not work with high carbon steels with their selection of carbon steels including only Wrought Carbon (WCB), LCB, LCC, 4130, and 4140 carbon steels. We then coordinated an in-person tour with Solidcast Co. and our point of contact, Jason Gutierrez, to get a better idea of the foundry and how they operate to see how we could collaborate to best bring our version of a George Washington Sword to life. Upon visiting the foundry, we inspected several parts casted by Soundcast and saw them conduct various manufacturing processes such as circular arc welding, pouring, and coating their cores. We also spoke with our point of contact to determine which alloy we would be using for our sword.

5b) Material Selection

Upon speaking with our point-of-contact, it was determined that our previous research did hold true with us mutually opting to use 4130 carbon steel as a casting because it mirrors properties of 4140 carbon steel which possesses good toughness, high fatigue strength, good strength and excellent hardness, as well as it's a great steel for high stress applications because it will not easily lead to fracture. [6] On top of these properties, we can heat treat and temper with 4130 to get to the properties of 4140 despite the 0.1% difference in carbon content, making up for that difference in the treatment phase of the project as well as 4130 being easier to heat treat than 4140 carbon steel due to it’s slightly lower carbon content that allows it to be slightly more ductile. The alloy also has just enough carbon content to be considered a medium carbon steel and offers us good strength without losing out on any properties such as good impact and abrasion resistance. We can also hot work the metal before it becomes hardened and difficult to work with. [7]

5c) Casting Process Selection

Soundcast specializes in sand casting and has the capacity to create green sand castings and resin sand castings. No bake casting was chosen for its higher surface finish and dimensional accuracy. Only one casting will be made so the lower cost and recyclability of the green sand casting is not relevant in this case. A binder jet 3D printer is used to create the mold instead of creating a more traditional pattern to reduce time and be able to provide higher dimensional accuracy in comparison to traditional sand castings. The cost per piece is higher with 3-D sand printing but given it’s one sword, it worked.

Figure 9: 3D printed sand mold

5d) Casting Process Overview

The casting process for our sword will begin with using binder jet 3-D printing practices to produce our mold and respective pattern using the ExOne S Max 3-D sand printer which will layer and produce our copes and drags with the mold cavity of our sword using Silica Sand for our sand of choice and Furan resin to bind the sand together and ensure our mold cavity will be well put together and hold its shape being as firm as possible once the cope and drag are put together and we prepare to pour our 4130 Carbon steel. Upon completion, our molds will be sent out to SoundCast Co. and subsequently will begin pouring upon its arrival. Using a spectrograph, SoundCast Co. will determine the ratio for each alloying element that will be combined with its 4130 Carbon steel. The ratio is sometimes correct on the first attempt; however, sometimes multiple adjustments are needed to perfect the blend. With the spectrograph, it is determined that for our 4130 Carbon steel, there is slightly more Chromium than is within our acceptable upper limit of 1.10% as we were at 1.15% so adding in Iron will help us to fall within our lower limit.

Carbon content was below our lower limit for Carbon at 0.166% when the lower limit 0.25%, so additional carbon was added to the mix.

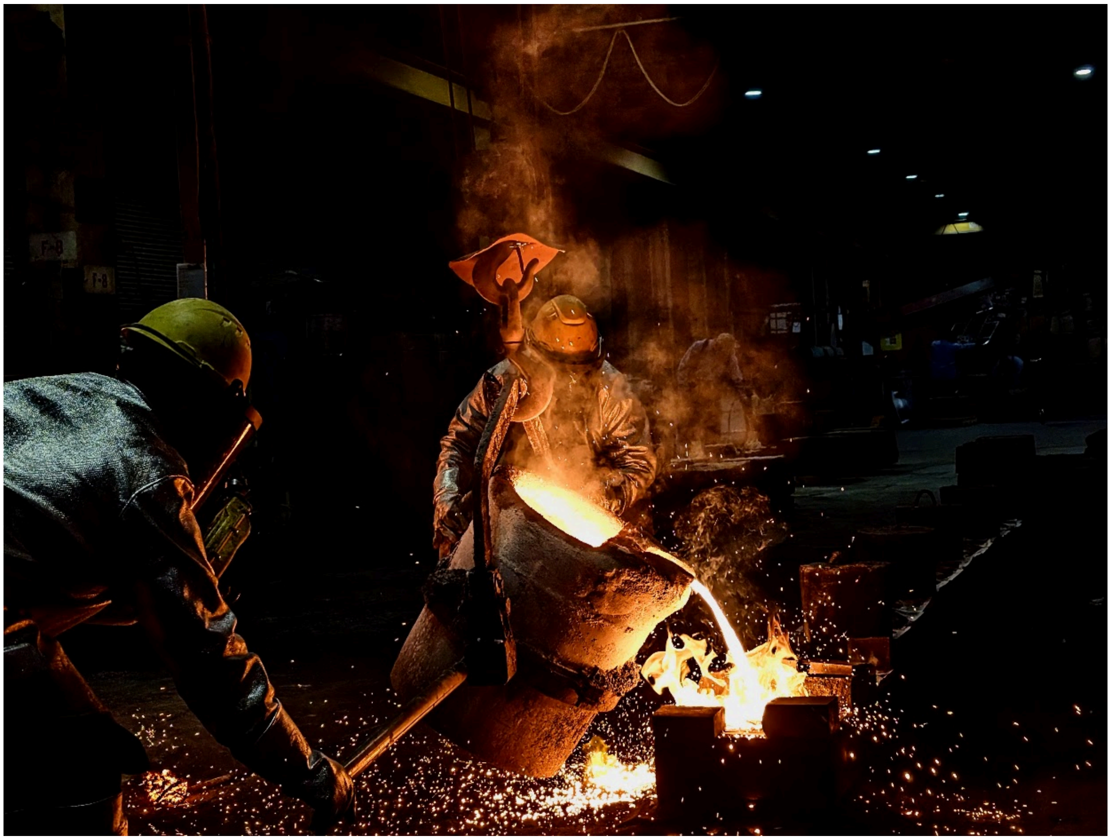

Figure 10: Pouring molten steel into the mold

Processing Phase

6a) Grinding and Polishing

Upon the receival of our sword from Soundcast Co., we began grinding and polishing after Soundcast provided us our sword after they cut the Risers and Gating. While grinding down our sword to get it within weight we found that our sword had porosity, possibly due to our mold not having the proper ventilation to cut out any potential oxidation. We picked up our backup casting sword and began grinding it using a DeWalt grinder. After grinding it, less pitting was found than the first casting and we chose to use this second casting to submit. Soundcast Co.

welded the pores to improve the finish and strength of the sword. Finally, we began to polish the sword using a polishing tool from DeWalt aiming for as close to a mirror finish as possible.

6b) Abrasion Testing

To evaluate the cutting efficiency of our sword, we conducted a series of controlled abrasion tests. As an initial assessment, we tested the blade on various fruits, inspired by the popular iOS game Fruit Ninja. Our primary goal was to determine how effectively the sword could slice through objects of different densities. For this test, we selected lemons and watermelons, both of which offer distinct resistances due to their varying textures and compositions. The sword successfully sliced through these low-density fruits with minimal resistance, demonstrating a sharp and well-crafted edge. The clean cuts and lack of significant tearing indicated that the blade maintained its integrity during impact. These preliminary results suggest that our sword possesses excellent cutting capability against soft targets.

Final Results

Our final sand casted part weighed a total of 4 pounds 13 ounces and a length of 38 inches casted in 4130 carbon steel.

Acknowledgements And Thank You

The Crucible Crew would like to thank California State Polytechnic University, Pomona and its Manufacturing Engineering club for the incredible opportunity to compete in this year's SFSA Cast in Steel competition along with SFSA for the incredible opportunity to develop and showcase our skills as manufacturing engineering students along with SoundCast for their hand in hand involvement with bringing our vision of our George Washington sword to life, regardless of the result.

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