2020 Steel Founders' Society of America (SFSA) Bowie Knife Competition Technical Report

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UNIVERSITY OF SOUTH ALABAMA

Submitted to

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This paper will discuss the justifications, design, and material selection used in the making of the specified Bowie knife. This knife was devised and fabricated by the University of South Alabama's students in collaboration with our sponsor, Howell Foundry.

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1. Introduction

It is believed that Rezin P. Bowie, James Bowie's brother (where James Bowie is displayed in Figure 1), was the creator of the first bowie knife [1]. The original design of the bowie knife was an 18 ⅜ inch large butcher knife with a thin blade and no silver mounts [1]. One fight made this tool famous, the Sandbar Fight. After the Sandbar Fight on September 19, 1827, witnesses and fighters of the battle described it as a "large butcher knife" and a "peculiar shaped and formidable knife" [1]. The story of the knife and its features swept the headlines and this tool was soon referred to as the Bowie Knife. In the popularity spike, other blacksmiths quickly started producing knives with similar features: a knife that had a coffin-shaped handle, heavy cross guard, and a sweeping clip-point blade [1]. Progressively, bowie knives shifted from the original straight blade, thick topline, no hand guard design to a more robust design with hand guards. [1]. As the rise of popularity continued, the length of the blade shortened from about 18 inches to a range of 8 ½ to 12 ½ inches, clip points (the curve at the top end of the blade) were adopted along with hand guards and wooden handles [1]. The blade became more effective in fights, easier to conceal and carry, safer to handle [1]. In the last century, spine jimpings (notches to provide grip), different blade ends (e.g. spear, tanto and trailing points) and material finishes were modifications used to make variations of bowie knives (see Figures 2a, 2b, and 2c for examples). These added alterations made the bowie knife a more versatile tool [1].

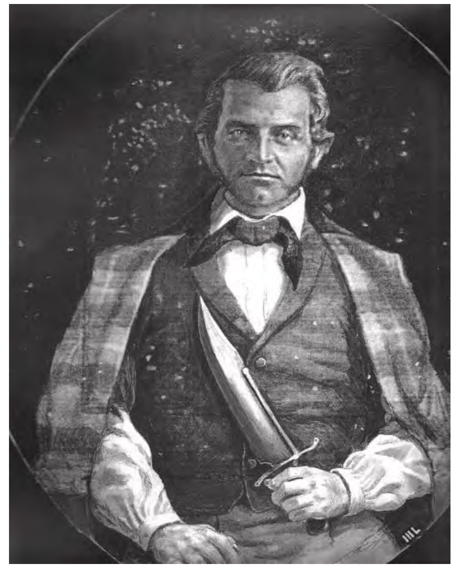

Figure 1. James Bowie [4]

Figure 2a. 1917 Frontier Bowie Knife [10]

Figure 2b. Uncle Henry Bowie with Stag Handle [17]

Figure 2c. Edwin Forrest Knife [18]

For this Bowie Knife competition, we sought to optimize all aspects of the traditional bowie knife by combining a historical design with modern advancements in metallurgy. As previously mentioned, hand guards were not a component in the designs from the early 19th century. Therefore, the design presented in this report did not have a hand guard. However, after the first phase of testing, the team decided that a guard needed to be included due to safety concerns. The displayed final design, Model J28, incorporated a hand guard that was constructed separately of the casted knife due to the constraints placed by COVID-19. The team received permission to enact this procedure as a secondary casting would not be possible under the given circumstances.

A. Project Management

The original project timeline is displayed in Figure 3 while the COVID-19 adjusted Gantt Chart is displayed in Figure 4. This team officially started in early mid-December with weekly team meetings to facilitate the exploration of innovative ideas, effectively collaborate, and share designs and ideas. Additionally, the team met with the Howell Foundry monthly to validate designs and expand upon discoveries until the COVID-19 inspired shutdown. The tasks were divided based on each team member’s strengths. Critical tasks were identified and assigned with corresponding deadlines.

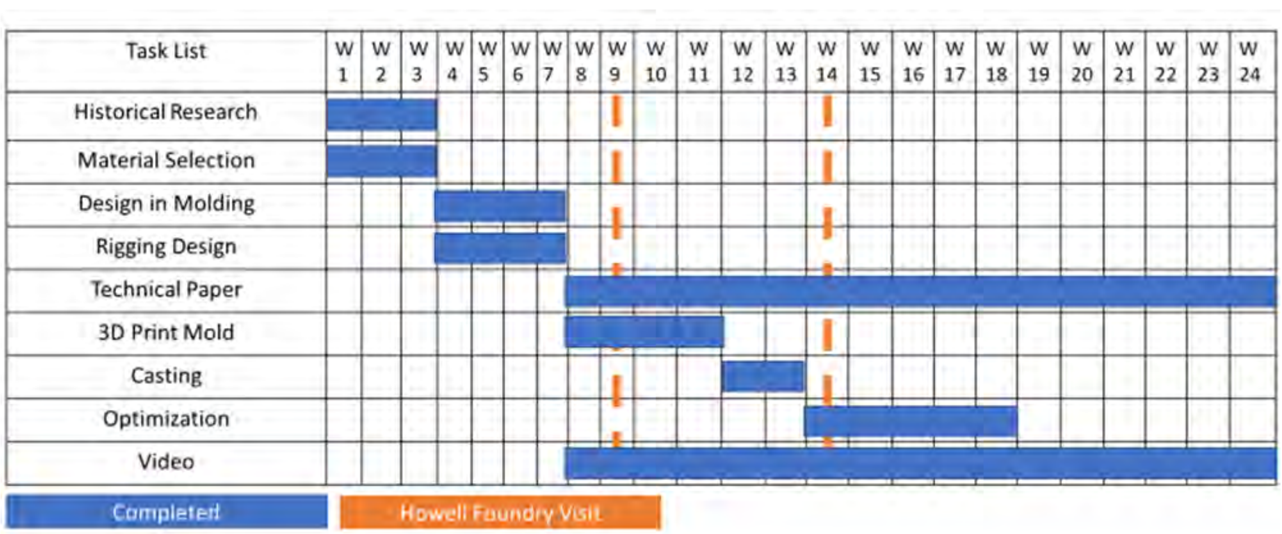

Figure 3. Planned Project Schedule

A more in-depth description of each task is as follows below:

1. **Historical Research.**
2. **Material Selection.**
3. **Design in Solidworks/Autocad (Critical Task).** The Bowie knife was designed using 3D Modeling software. Dimensional tolerances and an initial Bill of Materials will be determined. Decorative features for design uniqueness was incorporated into the knife.

Finite Element Analysis (FEA) will be conducted to ensure the product performs exceptionally.

4. **Rigging Design (Critical Task)**. Essential for improving the quality of casting. System design was determined after conversing with the Howell Foundry. Hand Calculations accompanied the selected design.
5. **3D Print Mold.** Based on the students design for the bowie knife and rigging design, the Howell foundry designed a 3D Printed Mold.
6. **Casting.** Actual casting of knife was made at the steel foundry. USA students visited the steel foundry to learn about the process and helped prepared the mold for the pouring.
7. **Optimization.** This process includes the Annealing Heat Treat, initial sharpening, polishing of the casted knife, Quench and Temper heat treatments, and final sharpening. After this, the team conducted non-destructive tests to ensure quality of design.
8. **Technical Paper.**
9. **Video.**

Due to the campus disruption caused by COVID-19, the original project plan was adjusted. Figure 4 shows the adjusted Gantt chart. To ensure the submitted products were completed on time, the team members shifted their responsibilities.

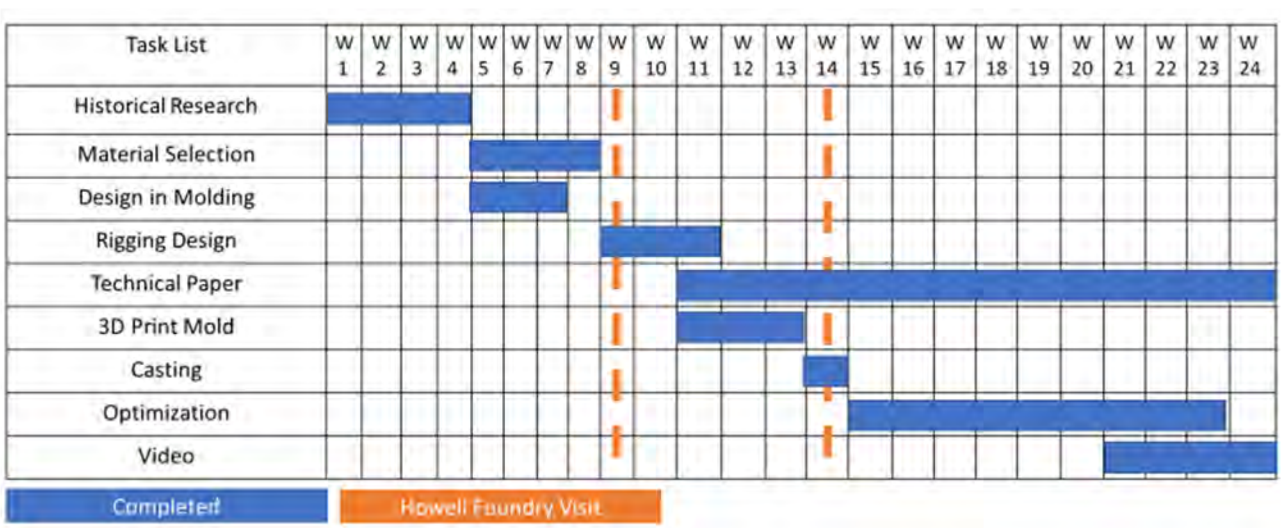

Figure 4. Adjusted Project Schedule

2. Material

Bowie knives are hunting knives typically used in situations such as butchering, slashing, and survival situations. Therefore, material properties such as strength (tensile, yield, and creep), hardness, toughness, and ductility were prioritized for the casting of the presented knife. Additionally, grain size is an important characteristic when describing a metal alloy because it influences the following material properties: hardness, yield strength, tensile strength, fatigue strength, and impact strength [5,12]. The grain size also affects the machinability during finishing [12]. Typically, there is an increase in the aforementioned properties when grain sizes become finer [12].

Martensitic stainless steel typically has a high chromium content and alloying combinations [7]. This allows for the crystal structure to convert from a ferrite to an austenite [7]. An austenite is a solution of carbon and constituents which forms a cubic structure when the steel is heated above critical temperature and quickly quenched [7]. For this reason, it is an ingredient in stainless steel typical for cutlery [7]. Specifically, martensitic stainless steel has desirable properties such as corrosion and oxidation resistance with high strength at low temperatures and creep resistance at elevated temperatures [6]. Therefore, a martensitic stainless steel was the chosen alloy for the specified bowie knife with a goal to form austenitic crystalline structures through heat treatment to affect the grain size of the material. After deliberating with the Howell Foundry, three specific types of alloys were chosen.

A. Material Option 1: CA15

CA15 has the highest ductility among most martensitic stainless steels, due to its high chromium (Cr) and high silicone (Si) content among the cast stainless steels [13]. The Cr content of the specified alloy ranges between 11.5 – 14 %, which has desirable benefits like improved corrosion resistance, wear resistance, and strength with heat treatment application [13]. The Si content of this alloy ranges until 1.5% [13]. The addition of Si can improve elasticity, strength, and oxidation resistance [13].

B. Material Option 2: CA15M

CA15M possesses the same amount of Cr as CA15. The difference between CA15 and CA15M is the Molybdenum (Mo) content which ranges from 0.15 – 1.0 % [14]. Mo aids in the tempering process [14]. CA15M has the highest thermal diffusivity among most martensitic stainless steels, which enables a lower melting point and the ability to cool the fastest [14].

C. Material Option 3: CA28MWV

CA28MWV has the highest fatigue strength compared to the mentioned materials [15]. It was modified for high temperature strength through its addition of Mo, Vanadium (V), and Tungsten (W) [15]. Mo increases corrosion resistance, hardenability at high temperatures, and tensile strength [15]. It also promotes electrical conductivity which would be used if the knife were to be accompanied by a sheath with a magnet to hold the knife in place [15]. V activates carbides (chemical compounds made up of a carbon and a metallic or semi-metallic element) that increases strength and retains ductility [15]. Similarly, W promotes carbides and refines grain boundaries and it also increases hardness [15]. The combination of all three elements would react together during the heat treatment process to provide adequate hardening and significant corrosion resistance [15]. This alloy possesses the same Cr content as CA15 and CA15M. The Mo and W content both ranges between 0.9 - 1.3% [15].

Table 1. Mechanical Property Values of CA15, CA15M and CA28MWV

	Tensile Strength		Yield Strength		Elongation	Reduction of Area	Average Hardness	Poisson's ratio
Grade	ksi	MPa	ksi	Mpa	min%	min%	Brinell	
CA15	90	620	65	450	18	30	220	0.28
CA15M	90	620	65	450	18	30	210	0.28
CA28MWV	140	965	110	760	10	24	330	0.28

Table 1 displays a comparison of some of the mechanical properties. These mechanical property values aided in the decision of the knife material. Tensile strength is how much stress the material can withstand before the material breaking under tension [2]. Typically, the higher the strength, the better the material can resist applied forces [2]. Maximum yield strength entails the maximum stress the material could undergo before permanent deformation [2]. Elongation is the strain at fracture due to tension and Poisson's ratio is the strain due to compression [2]. The knife also needs a high reduction of area, or ductility, so it can permanently deform in all directions and have a lesser chance of fracturing [2]. Hardness is defined as the resistance to permanent deformation before ductility is enabled [2].

Considering the objectives of casting quality, high performing knife, the material CA28MWV was chosen. Its elemental composition has especially given the knife an efficient amount of carbide compounds. Those carbides will enable our knife to sustain sharpness longer, produce cleaner cuts with limited damage to the blade [8]. Additionally, we sought to heat treat the martensitic stainless steel to form austenite grain structures. These grain structures are finer thus increasing the toughness of the material [12]. Toughness is important as it is defined as the ability of the material to absorb energy prior to fracturing.

The base chemistry of the material CA28MWV was determined based off the ranges specified in ASTM A743. Table 2 compares the targeted chemistry with the prepared material content.

Table 2. Chemistry of CA28MWV

	Ni	C	Mn	Cr	Mo	Si	V
Range	.5-1	.2-.28	.5-1	11-12.5	.9-1.25	1	0
Target Chemistries	0.75	0.22	0.75	11.25	0.95	0.5	0.23
Actual Chemistries	.749	.218	.746	11.22	.945	.489	.226

NI-eq	Cr-eq
7.725	13.065

The chemistry was then further refined by making sure that the Ni equivalent and Cr equivalent calculations fell within the Martensitic range on the Schaeffler diagram. We also used the Ferrite Calculator provided by the SFSA wiki to make sure that there was no ferrite calculated in chemistry and evaluated its Ni and Cr equivalent against the Schaeffler diagram as can be seen in Figure 5a and 5b. The Schaffer diagram is used to estimate in which phase a given composition of stainless steel reaches a stable phase.

= Target Chemistries Calculated from Formulas on Schaeffler Chart

= Target Chemistries from SFSA Calculator

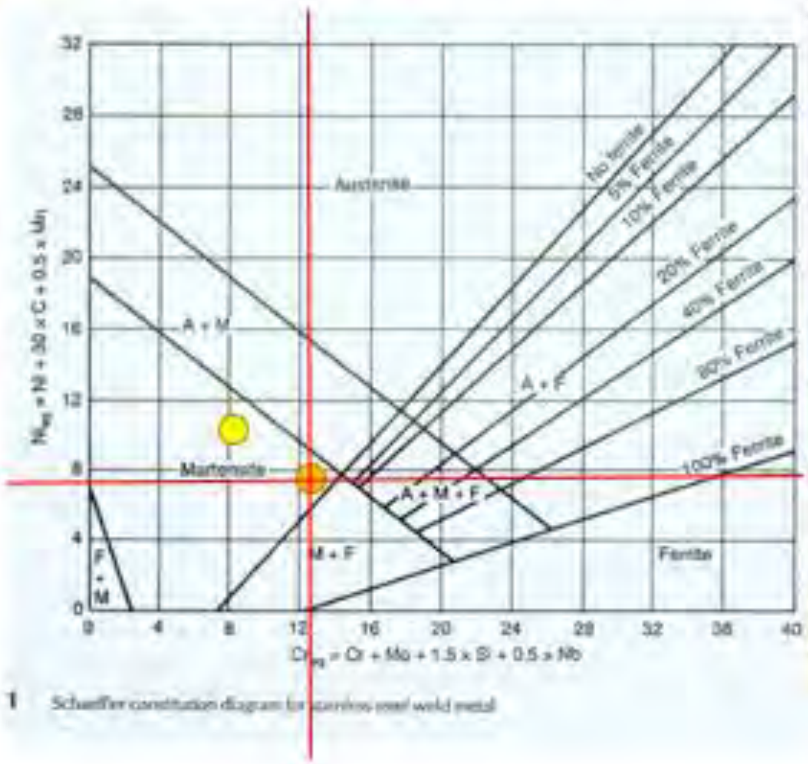

Figure 5a. CA28MVW Chemistry Schaeffler Diagram

Figure 5b. SFSA Calculator

3. Molding:

The team worked in collaboration with the Howell Foundry to create the mold that would be used in the casting of the knife. The agreed upon method for the mold creation was by 3D printing for efficiency and precision. Figure 6 and 7 show the result of that collaboration.

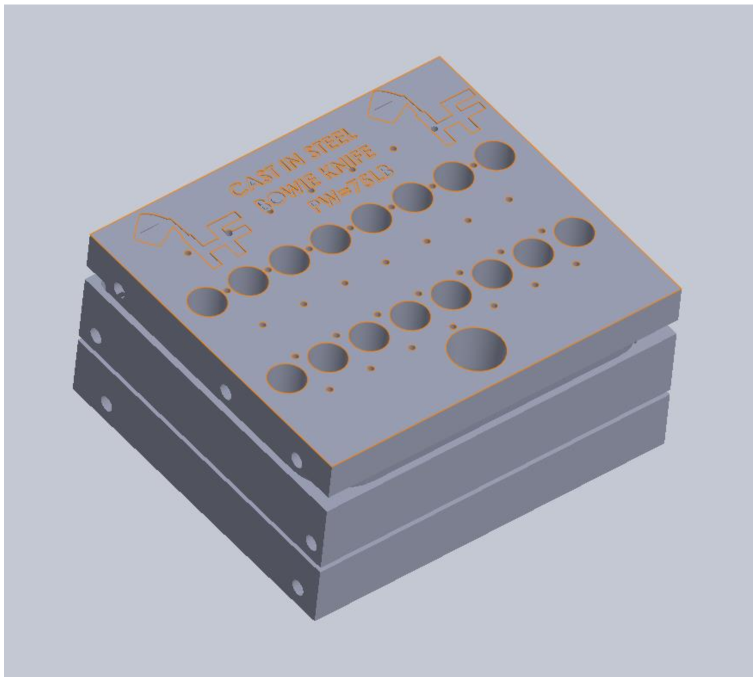

Figure 6. Top View of the Mold in SOLIDWORKS

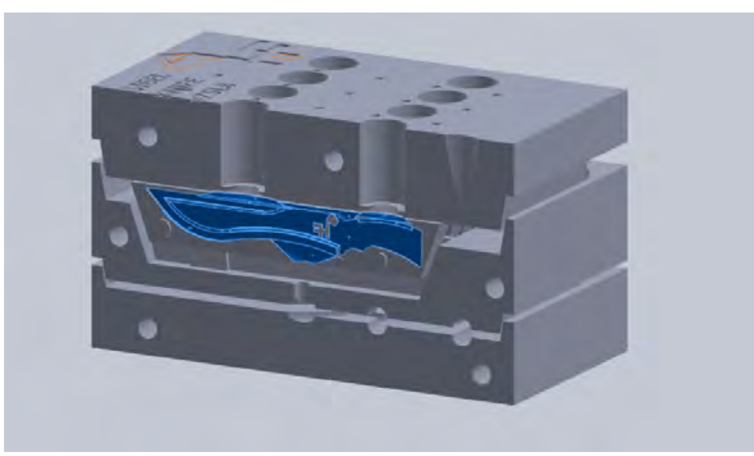

Figure 7. Top View of the Mold in SOLIDWORKS

4. Casting

Prior to casting, the Mold was fully dried and then preheated to ensure a minimally humid casting environment. The chosen material of CA28MWV had not ever been poured by Howell Foundry and some information had to be gathered during the melt process such as the liquidous and pour temperature. A liquidous temperature was established at approximately 2500°F. The liquidous temperature was determined during the melting process by measuring the temperature of the melt just as the last bit of metal was melted into solution. The addition of W was added early in the melt as it takes a considerable amount of time to dissolve into solution at a low liquidous temperature. An argon blanket was used to limit atmosphere exposure on the metal during heating. The V was added last. The pour temp of 2700°F was established based off the addition of W and the liquidous temperature as the specified temperature was determined to be the temperature in which W was fully capable of going into solution. The key to a good pour temperature is pour the metal as cold as possible without it freezing off in the mold cavity. This allows the metal to absorb less unwanted elements from the atmosphere during the melt and pour process.

Once all of the elements were melted, the foundry took a sample and analyzed it on an optical emission spectrometer. The readout showed that the melt met the established chemistry and the part was poured as shown in Figure 8.

Figure 8. Casting of the Bowie Knife

5. Design Process

During the beginning stages of the project, each group member researched and chose historical designs. Several of the selected designs had common features like the curvature angle in the blade's edge, a handle shaped for a secure grip, and a blade thickness of around $^1/_8$ inches. AutoCAD Inventor was the software chosen by the team's lead designer to model the knife. The designer had more experience utilizing this type of CAD software; therefore, he was able to render several different designs in a time efficient manner. Three separate AutoCAD models were created and adjusted to the parameters set by competition's organizations. Due to the team's familiarity with the drafting tool AutoCAD, the team chose to use the specified software. The parameters are that the body could be no shorter than 9 inches but no longer than 14 inches. The group decided that the body would be 10 inches length, 2 inches height, and $^3/_{16}$ inches thickness as can be seen in Figure 9. The handle, also referred to as the tang, was determined to be 4 inches in length complimented with a $^1/_4$ inches by $^1/_8$ inches slot to position a hand-guard.

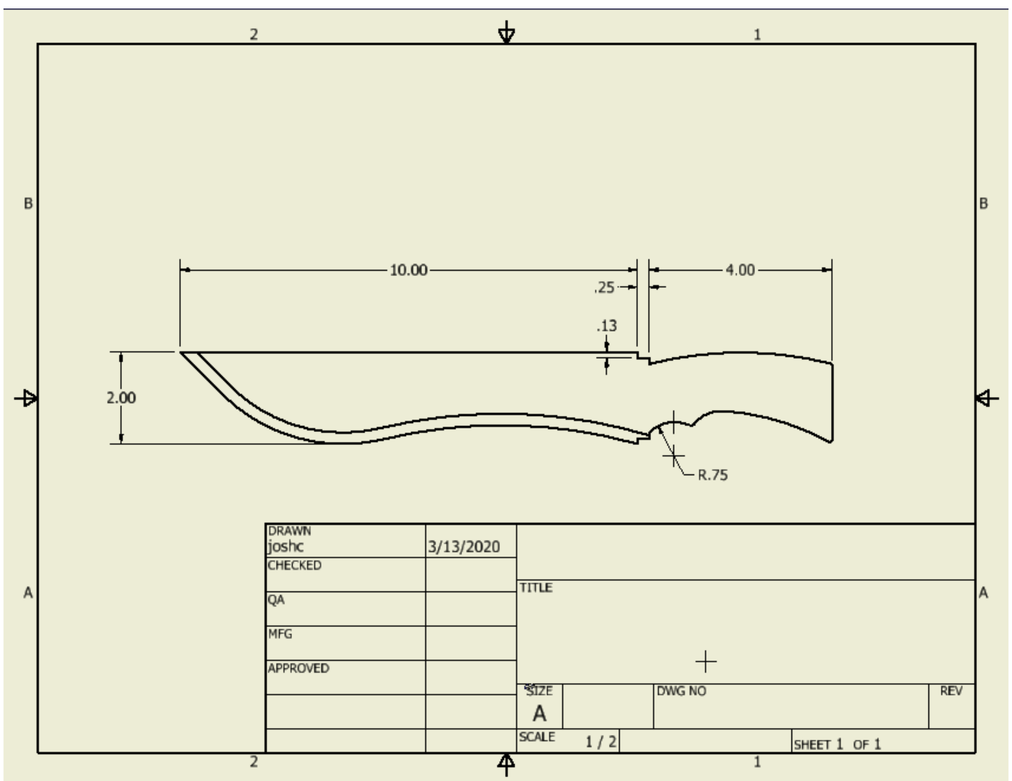

*Figure 9. Autodesk Inventor Model's finalized dimensions. *The only relevant dimension excluded is the $^3/_{16}$ inch thickness of the entire knife*

When designing the blade model in AutoCAD, we focused on using the blade's curvature to help maintain the sharpness during use. Considering the blade tip's integrity and historical characteristics, an ideal angle between the spine and the cutting edge was identified to be 45° (or -315° using the tip as the origin of a standard cartesian plane). It was found that the 45° tip angle would help evenly distribute the stress on the model when simulating our "stabbing-test" and "impact test" with Finite Element Analysis (FEA) (described in the following section).

Once the blade's body was completed and approved by all team members, focus was then directed toward the angle of the blade. According to multiple knife-vendor articles, the industry's recommended angle of sharpening was determined to be approximately 25° (12.5° on each side of blade). We used this recommendation as a reference point and verified using FEA.

Lastly, the tang was the final part of the knife to be drawn onto the CAD model. The initial shape of the tang was a simple elongated-oval styled shape but after further consideration, the presented design was identified to provide more leverage for the user. Figure 10 displays the final design with additional embellishments such as the logo.

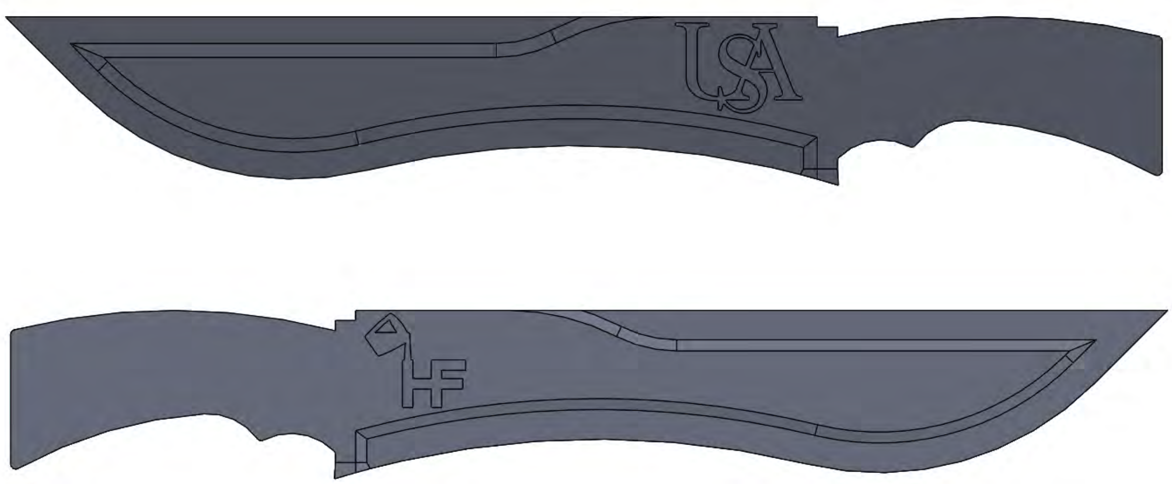

Figure 10. Final Design of Bowie Knife in AutoCAD

6. Rigging

A stage in which much consideration must be considered is the rigging. Rigging is the process of using channels, ingates and risers on a mold to distribute the flow of molten metal into mold cavities [3]. Once the molds are filled with the molten metal and the cooling process starts, the metal will shrink [9]. Rigging allows the final mold to be filled even after the shrinkage occurs by using risers with 2 - 5% more molten metal [9]. Risers are placed at the top of the molds so the metal can drain down to the mold during the cooling process [9]. Ingates are inlets that directly feed the molten metal into the mold [9]. Figure 11 displays the riser design for the bowie knife where the simple shape chosen was a rectangular prism. We found that we needed 2 risers of 1.5 inch diameter for each knife. Detailed calculations are provided in Appendix D.

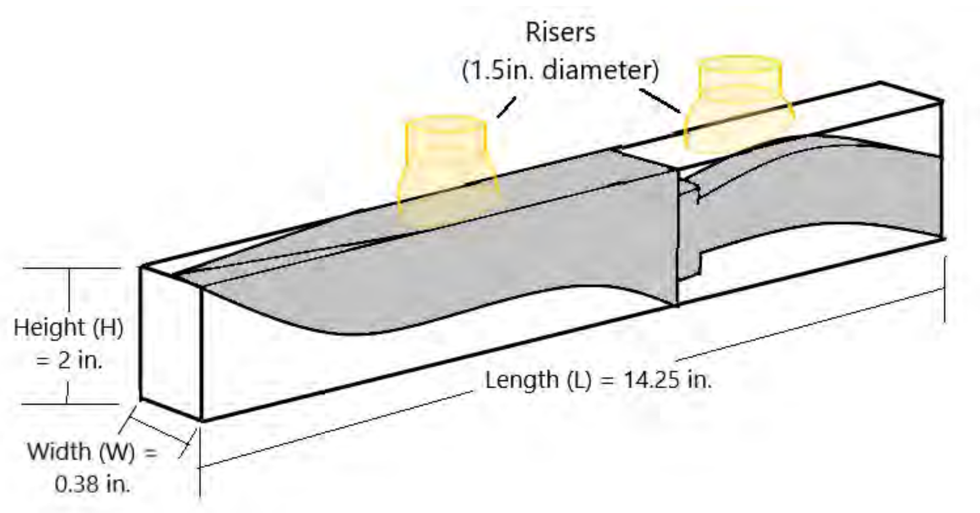

Figure 11. Preliminary Riser Design

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To ensure the calculations are accurate so the rigging process is successful, the following conditions take into consideration:

- The modulus of the riser must be larger than the modulus of the casting so the riser can solidify last and fulfill its purpose.
- The modulus of the ingate must be smaller than the modulus of the casting so the ingate can solidify first.
- The ingate must be thinner than the knife so when it is time to be removed, the ingate at that point would not damage the knife's structural integrity.

The knife was irregularly, but symmetrically, shaped. We used a simple shape to model the knife to simplify the computations a receive a close approximation. The alternative is to model utilizing multiple complex shapes that would provide more accurate results but would require more time and computing power. The final rigging design can be seen in Figures 12, 13, and 14. Additional supporting Figures are in Appendix B.

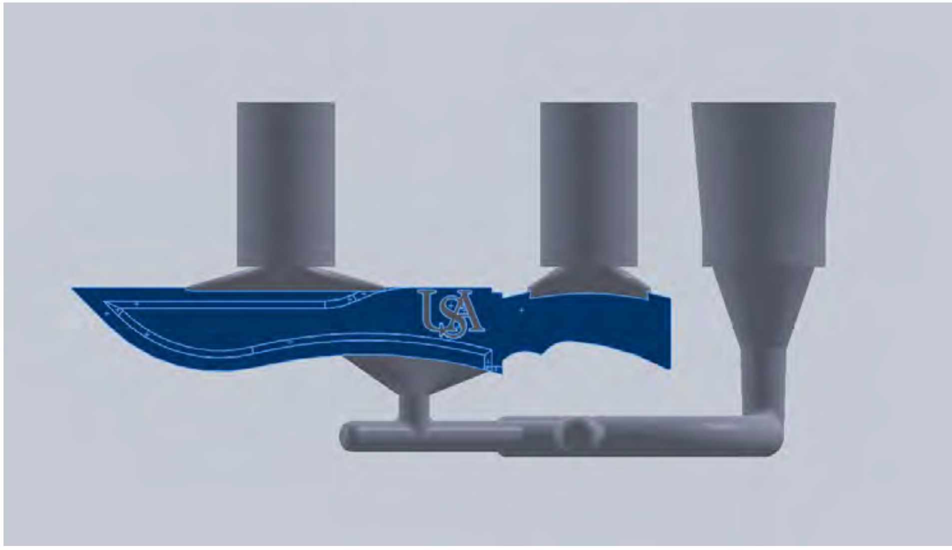

Figure 12. Side View of Rigging Design

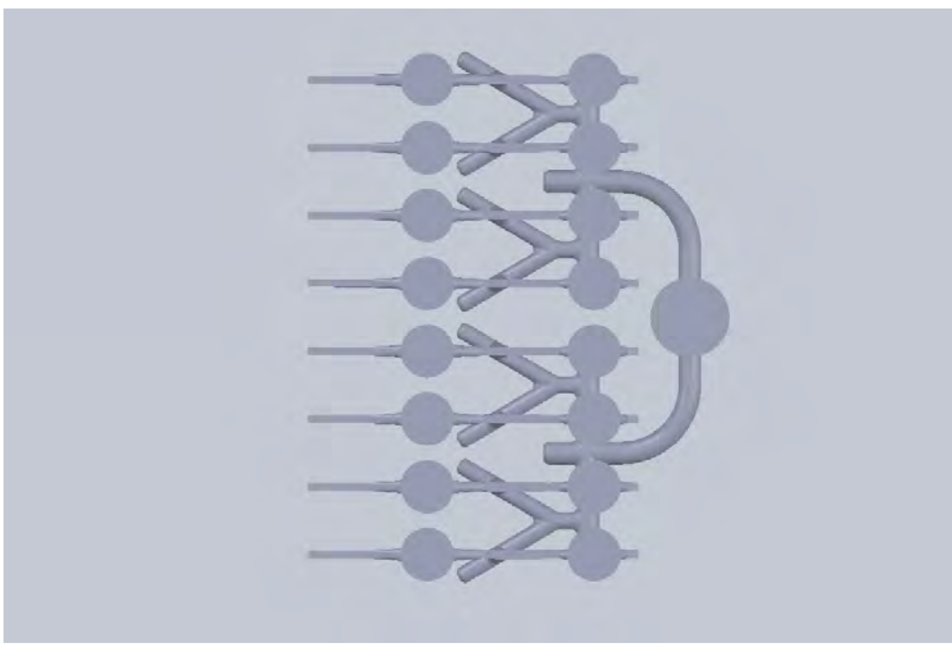

Figure 13. Top View of Rigging Design

Figure 14. Preliminary Product after Casting

7. Engineering Simulations: Finite Element Analysis (FEA)

Finite Element Analysis (FEA) is widely utilized to simulate instrument performance using the numerical technique called Finite Element Method. This tool is used to reduce the number of prototypes needed to optimize the product's design and improve efficiency. SOLIDWORKS and Autodesk Inventor were used to model our Bowie Knife options and test our designs. Based on previous studies [10], our design was tested with 150N of force (~ 34 Ibs).

The design was meshed with the material CA28MWV to simulate the potential stresses after load. As displayed in Figures 15 and 16, it was simulated a force impacting the tip of the blade and the edge. The Von Mises Stress is displayed where the max pressure was 24.1 x 103psi (~165MPa). The elastic modulus of the material is 28 x 106psi (~200GPa) and the fatigue strength is 69 x 103psi (~470MPa).

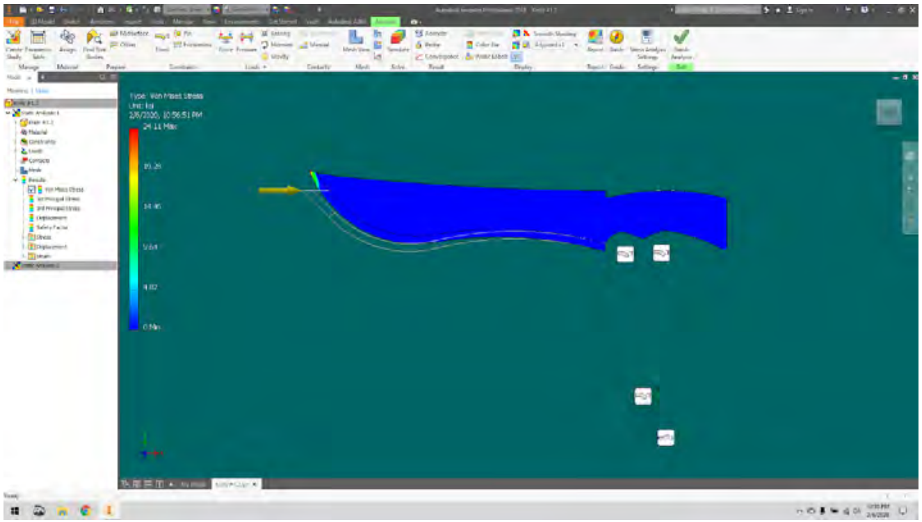

Figure 15. Stabbing Test

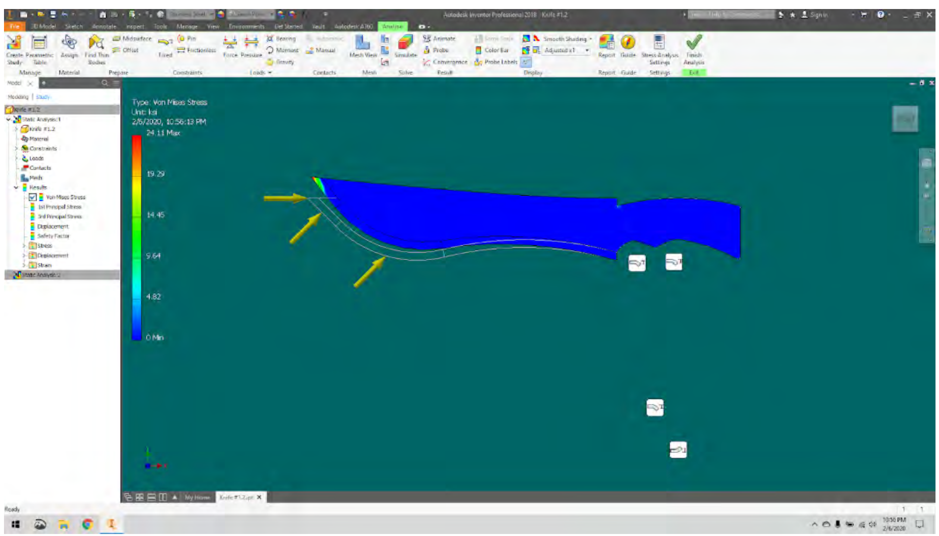

Figure 16. Impacting Test

8. Post-Processing

To begin the sharpening process of the knife, first the mill-scale from the casting process had to be removed. The mill-scale appeared as a rough dark gray textured surface that was formed when the liquid metal entered the mold and contacted the sand. Technically this is not mill-scale due to most references of mill-scale are mentioned regarding hot rolled steel but is basically the same concept for a cast product. The removal of this mill-scale was achieved by using a stationary “belt-sander” with a belt of the following dimensions: 2-inch x 48-inch (60 grit). The belt used during the mill scale removal is a product of Saint-Gobain Abrasives, LLC.

After the mill-scale removal was complete, the first (coarse) sharpening of the blade was applied using the same 60 grit abrasive belt as previously mentioned. The angle of sharpening for the entire blade was approximately 25° (12° to 13° each side). After finishing the coarse sharpening, a finer grit abrasive was used to get a more polished look on the entire knife and a sharper blade edge. This finer grit was a polishing stone used on an air grinder that was approximately 6000 grit. This ended up being the final polish and sharpen prior to heat treatment.

Figure 17. Pre- Heat-Treated Blade

Figure 18. Close-up of the Pre- Heat-Treated Blade

A. Handel/Guard

When preparing the tang for the wood pieces of the handle, the tang had two $^3/_{16}$ inch holes that were drilled prior to heat treatment. The wood for the handle is red oak and was treated with wood hardener prior to installation. The red oak pieces were attached to the tang in two separate ways. First, JB Weld epoxy was applied to bond both red oak pieces of the handle directly to the tang. Second, two brass rods of $^3/_{16}$ inch diameter were inserted through both pre-drilled holes. The rods were then air hammered to make them act like rivets in the handle essentially securing the handle from succumbing to shear forces when using the knife in a stabbing and/or chopping motion. After installing the rivets and allowing the epoxy to completely dry, the red oak was then sanded and stained using a "Gun Stock" color with two coats. The guard and pommel were made from a pure copper bar and shaped entirely by hand using a sanding pad on a right-angle grinder then polished using a buffer wheel. The guard dimensions are the following: 5 $^3/_4$ inch height, 1 $^1/_4$ inch width, and $^1/_8$inch thick. The pommel dimensions are the following: 1 $^3/_{16}$ inch height, $^5/_8$inch width, and $^1/_4$ inch thickness. The pommel adds an additional $^7/_8$ inch in length to the entire knife which results to final overall knife length of 15 $^1/_8$ inch. Upon the knife being completely assembled, the final sharpening was applied using a "wetstone" until the desired sharpness was achieved.

B. Heat Treatment

Prior to any grinding or sharpening, the knives needed to be annealed. This is due to the as-cast Brinell of 555. The knives would have been too hard and brittle to work on in this state. There were multiple attempts to anneal the knives to achieve a lower Brinell. Finally, an annealing temperature at 1425˚F then oven cool was successful at reducing the Brinell down to 270 as described in Table 3.

After the knife's blade was sharpened and polished, it needed to undergo a Hardening heat treat to bring the Brinell hardness back up and then a Temper to reduce brittleness and increase toughness. Since the ASTM Standard did not specify a specific heat treatment temperature, but gave a range of 1875 -1950˚F, we used 1920˚F to ensure all intergranular constituents entered solution and then Air Quenched. The final Brinell was 340 after the Hardening and Tempering. This was the expected Brinell after Heat Treating. These steps were supported by Figures 19, 20, and 21.

Table 3. Heat Treatment of CA28MWV

	Anneal	Hardening	Tempering
Temperature:	1425°F	1950°F	1200°F
Ramp Time:	1 Hr	Ramp to 1000°F hold for 30 min. Then ramp to 1450°F and hold for 30 min. Then ramp to 1950°F and hold for an hour.	1 Hr
Soak:	1 Hr	1 Hr	1 Hr
Cool Time:	Oven Cool (See Chart)	Air Quench (Fan)	Air cool in still ambient
Brinell Hardness:	270	460	340

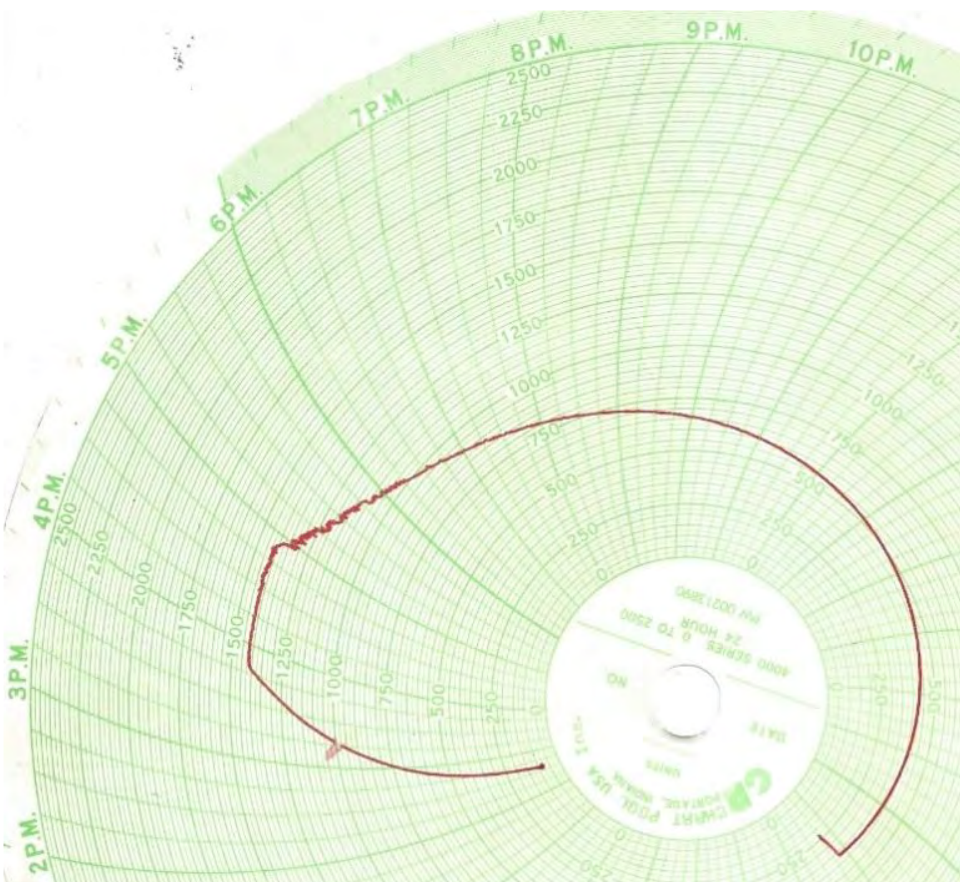

Figure 19. Anneal Heat Treat Chart

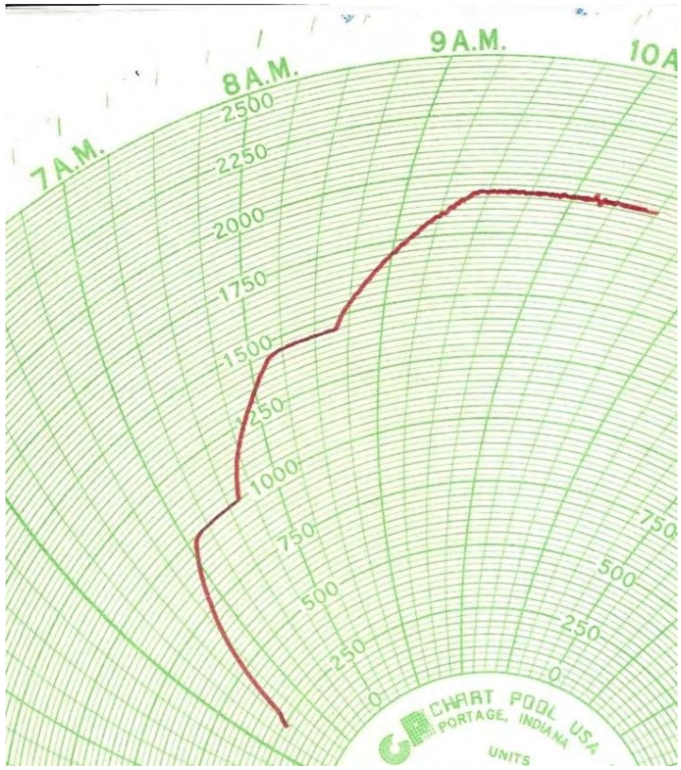

Figure 20. Harden Heat Treat Chart

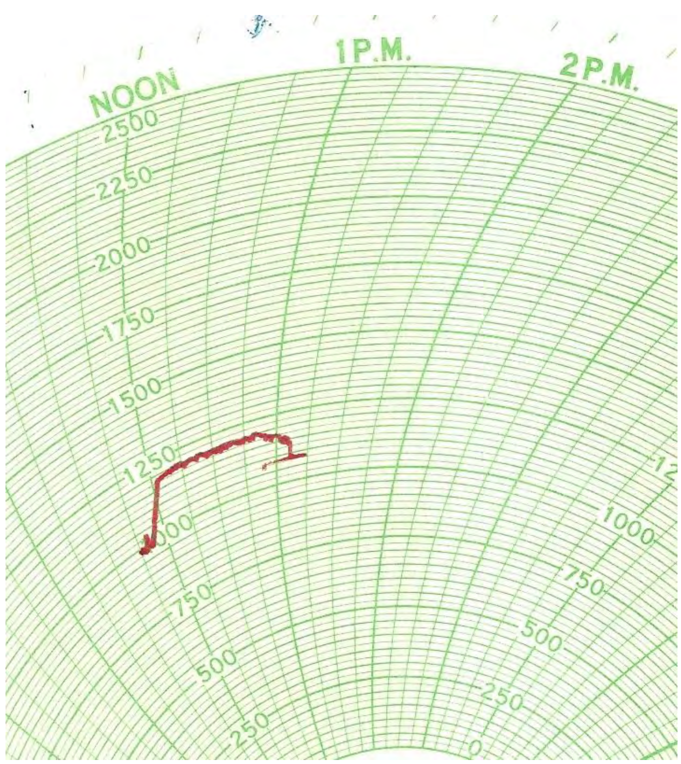

Figure 21. Temper Heat Treat Chart

9. Testing

The following are the results from 3 independent test bars pulled at varying stages of heat treatment (Cast, Normalized, Quench and Tempered). This procedure is important to determine the effects of the Heat treatment to the metal properties. For CA28MWV, the ASTM Standard specifies the following requirement:

- Tensile – 140
- Yield – 110
- Elongation – 10
- Reduction of Area – 24

From the results we concluded that the final product came close to the expected properties as Tensile and Yield Strength met the ASTM Standard. Elongation and Reduction of Area were below the specified property value. Therefore, the metal is expected to be marginally brittle.

10. Challenges

This section describes the major challenges during the development of the knife.

A. Thickness

The initial thickness of the knife was chosen by team based off research. Howell Foundry recommended adding a slight taper to help with the cast-ability of thin section and the soundness of the blade post cast. Before pouring, we ensured that there were no grains of sand present that could affect the integrity of the knife after the metal was poured into the mold. Additionally, we had to develop a riser strategy in which the metal would travel to all portions of the mold. Then we identified the orientation of the mold is needed to ensure completeness of design. We chose to orient the mold vertically to ensure the metal spreads to all edges of the mold with a slow, laminar flow (less than 25 in/second). We taper it down based on the natural liquid in gravity for minimal air.

B. Grain Size & Restructure

Then casting, the grain size is generally large which contributes to a decrease in strength and toughness of the metal. To resize or restructure grain sizes, we elected to heat treat the metal to increase the strength and toughness of the metal according to ASTM A743/A743M. We chose to use a material that possesses Tungsten, Vanadium, and Molybdenum to refine the grain size, add strength, and help prevent corrosion.

C. Material Selection

The material we chose could be consider heavy for the application as the density is roughly 7.9 g/cm^3. After the initial sharpening (which is prior to heat treatment), the knife weighed roughly 1.9 pounds where typical bowie knives weigh 0.9 pounds. To counteract the weigh imposed by the blade portion of the knife, we decided to counterbalance the design at the tang with brass. This brings the center of gravity back toward the tang.

D. Rigging Design

The shape of the knife being casted was irregular. Taking this into account, the design had to transition from a detailed multi shaped mold to a simpler one. The shape of the risers had to modify from universal circle to oval. Additional consideration were oxidation effects, smaller back pressure, and counter gravity system.

11. Finish Product

It is our team's belief that the University of South Alabama's and Howell Foundry's bowie knife, now called Model J28 (see Figure 22), will perform well regarding strength, sharpness, and durability. The unique material CA28MWV will help our knife retain its desirable properties, and with the additional heat treatment will help further the retention of these properties. With the team's consideration of historical influences, technical design, and help from the Howell Foundry LLC, we hope that Model J28 exceed expectations.

Figure 22. Model J28

12. Acknowledgments

The University of South Alabama 2019-20 Cast in Steel Team would like to express our deepest gratitude to the Howell Foundry LLC for their support. Mr. Joseph Hutto's guidance, expertise, and support was crucial for the successful creation of the submitted Bowie knife. We would also like to express our deepest gratitude toward to Drs. David Nelson and Melike Dizbay-Onat from the William B. Burnsed Jr. Department of Mechanical, Aerospace, Biomedical Engineering. The resources and support they provide was also essential for the timely completion of this project.

Mr. Joe Hutto
Howell Foundry LLC

Dr. David Nelson
University of South Alabama

Dr. Melike Dizbay-Onat
University of South Alabama

13. References

1. R., W. (2010, June 12). BOWIE KNIFE. Retrieved May 21, 2020, from https://tshaonline.org/handbook/online/articles/lnb01
2. “Stress – Strain Relationships.” OPTI 222 Mechanical Design in Optical Engineering. 21 May 2020.
3. “A Design Study in Steel Castings -- Pintle Socket.” Rigging Design, www.sfsa.org/tutorials/pintlesocket/Pintle_17.htm.
4. Lemon, M. (2011, June 17). James Bowie. Retrieved May 21, 2020, from https://fineartamerica.com/featured/james-bowie-mark-lemon.html
5. Hibbeler, R. C. (2003). *Mechanics of materials*. Upper Saddle River, NJ: Pearson Prentice Hall.
6. Garrison, W. (2003, January 01). Stainless Steels: Martensitic. Retrieved May 21, 2020, from https://www.sciencedirect.com/science/article/pii/B0080431526015825
7. The Editors of Encyclopaedia Britannica. (2013, April 29). Austenite. Retrieved May 21, 2020, from https://www.britannica.com/technology/austenite
8. Shaddy, Wade. The Advantages of Carbide Cutting Tools. 7 Oct. 2016, homeguides.sfgate.com/advantages-carbide-cutting-tools-99598.html.
9. Feeding & Risering Guidelines for Steel Castings, Steel Founders' Society of America, Barrington, Illinois, 2001
10. Nolan, Gary, et al. “Forces Generated in Stabbing Attacks: an Evaluation of the Utility of the Mild, Moderate and Severe Scale.” International Journal of Legal Medicine, vol. 132, no. 1, 2017, pp. 229–236., doi:10.1007/s00414-017-1702-7.
11. “1917 Frontier Bowie Knife.” Atlanta Cutlery. Retrieved May 21, 2020. www.atlantacutlery.com/1917-frontier-bowie.
12. Herring, Daniel H. “Grain Size and Its Influence on Materials Properties.” The Heat Treat Doctor, Industrial Heating, www.heat-treat-doctor.com/documents/GrainSize.
13. “Iron Alloy.” ACI-ASTM CA15 (SCS1, J91150) Cast Stainless Steel :: MakeItFrom.com, 30 May 2020, www.makeitfrom.com/material-properties/ACI-ASTM-CA15-SCS1-J91150-Cast-Stainless-Steel.
14. “Iron Alloy.” ACI-ASTM CA15M (J91151) Cast Stainless Steel :: MakeItFrom.com, 30 May 2020, www.makeitfrom.com/material-properties/ACI-ASTM-CA15M-J91151-Cast-Stainless-Steel.
15. “Iron Alloy.” ACI-ASTM CA28MWV (J91422) Cast Stainless Steel :: MakeItFrom.com, 30 May 2020, www.makeitfrom.com/material-properties/ACI-ASTM-CA28MWV-J91422-Cast-Stainless-Steel
16. “Tips for Selecting the Right Bevel Angle.” SharpeningSupplies.com, www.sharpeningsupplies.com/Tips-for-Selecting-the-Right-Bevel-Angle-W44.aspx.
17. Stec, Peter. “The 5 Best Bowie Knives.” The Outdoor Magazine, 20 Feb. 2020, knifeup.com/the-best-bowie-knives-ever-made/.
18. “Reproductions.” *Lucas Forge*, Retrieved May 21, 2020. customhuntingknives.org/models/reproductions/.

14. Appendix

Appendix A: Casting

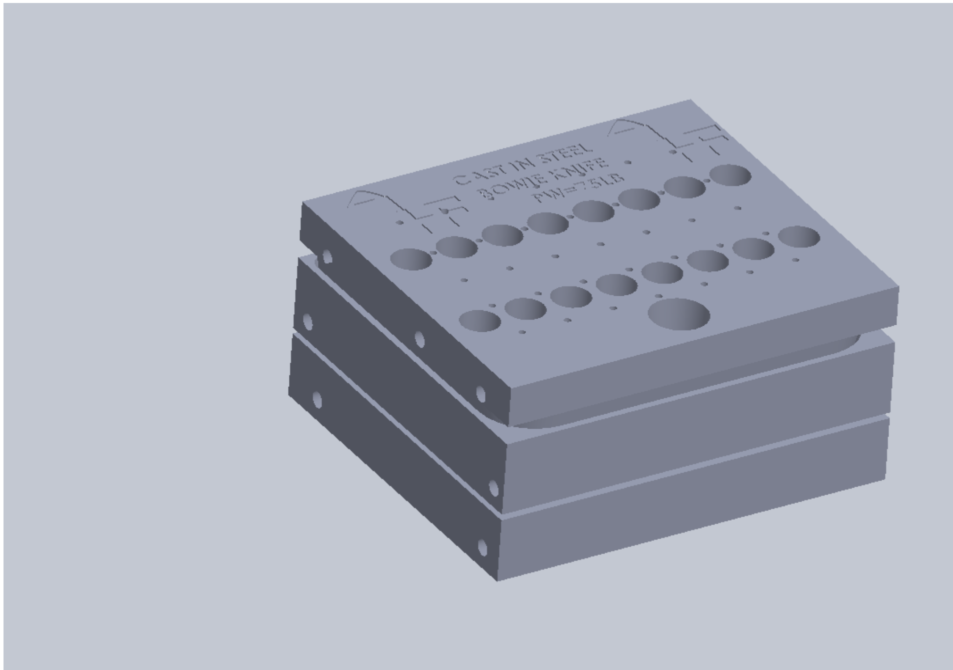

Figure 23. Final Layer of Mold

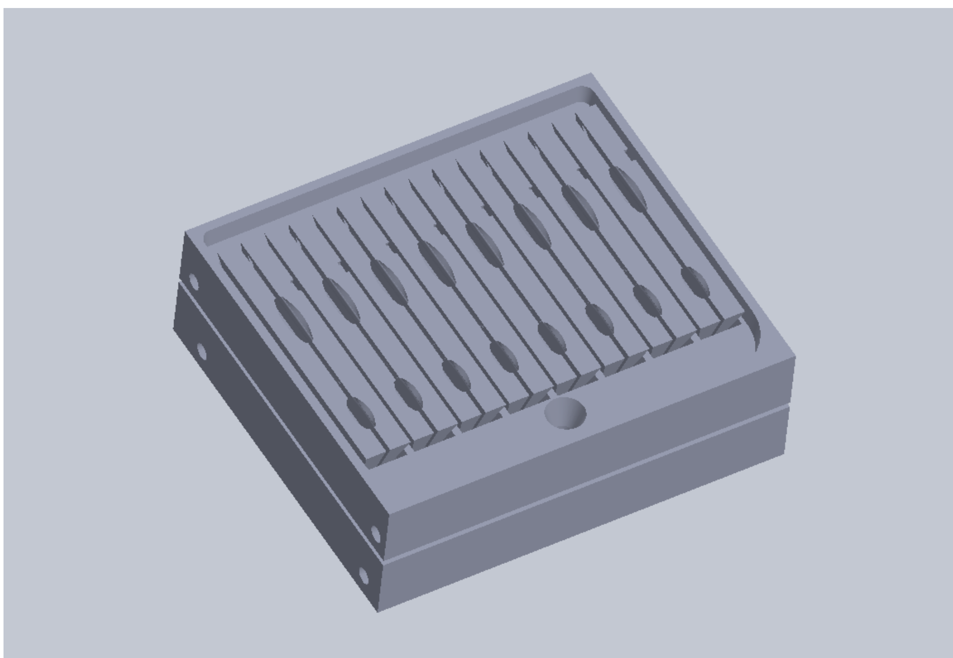

Figure 24. Second Layer of Mold

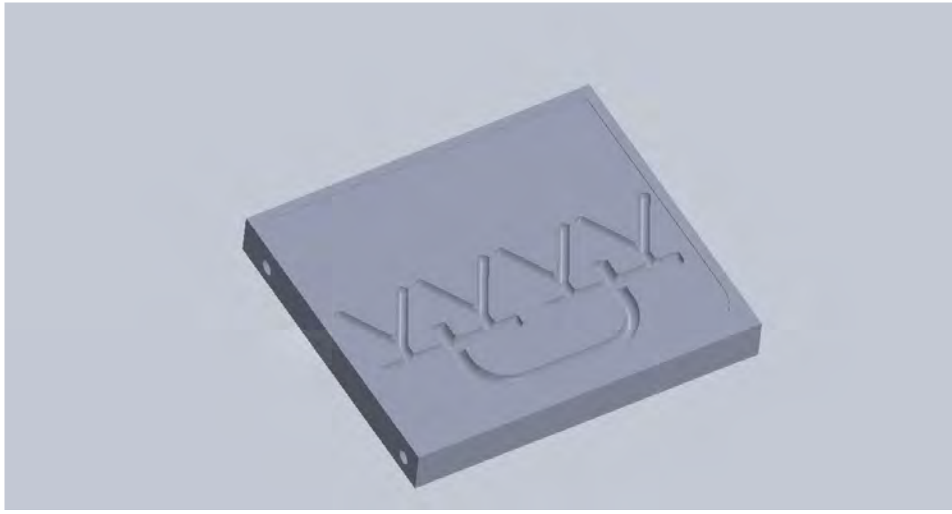

Figure 25. First Layer of Mold

Figure 26. Crossection of Mold

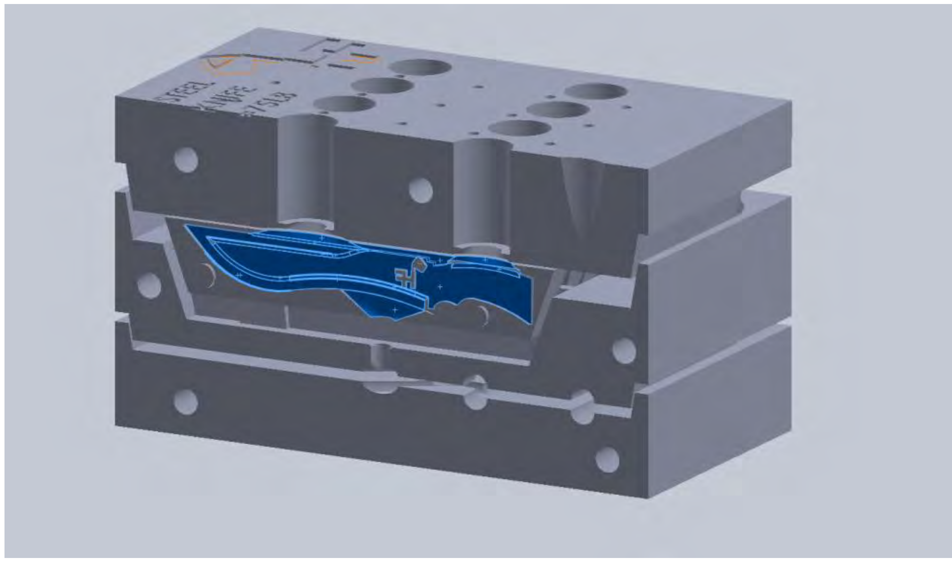

Figure 27. Front View of Mold

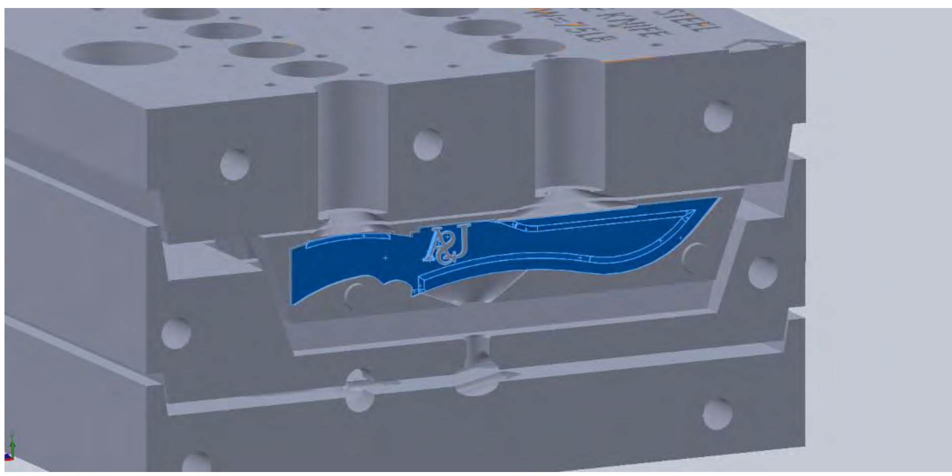

Figure 28. Back View of Mold 1

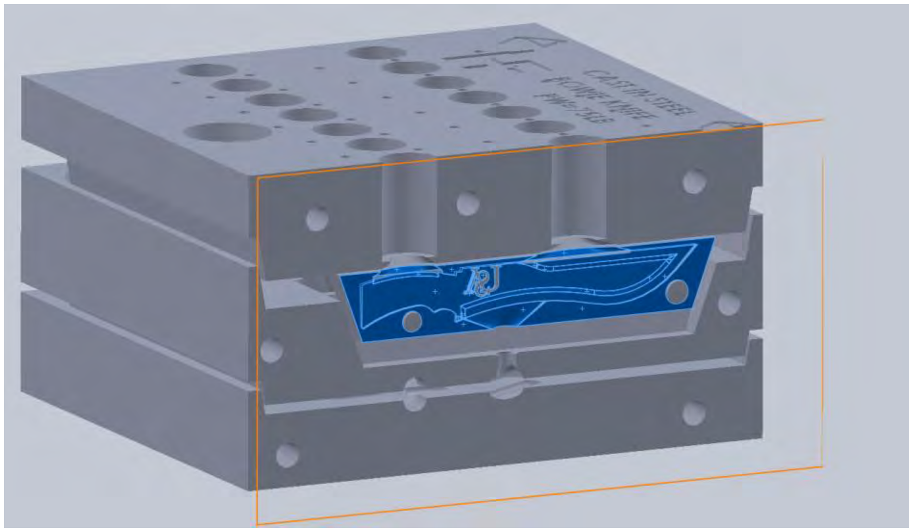

Figure 29. Back View of Mold 2

Appendix B: Rigging

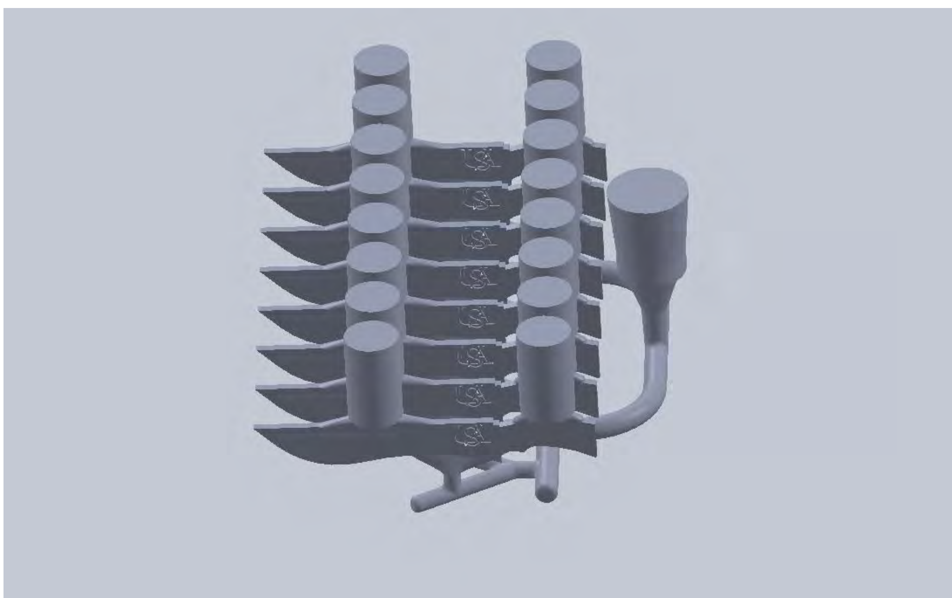

Figure 30. Top View of Rigging Design

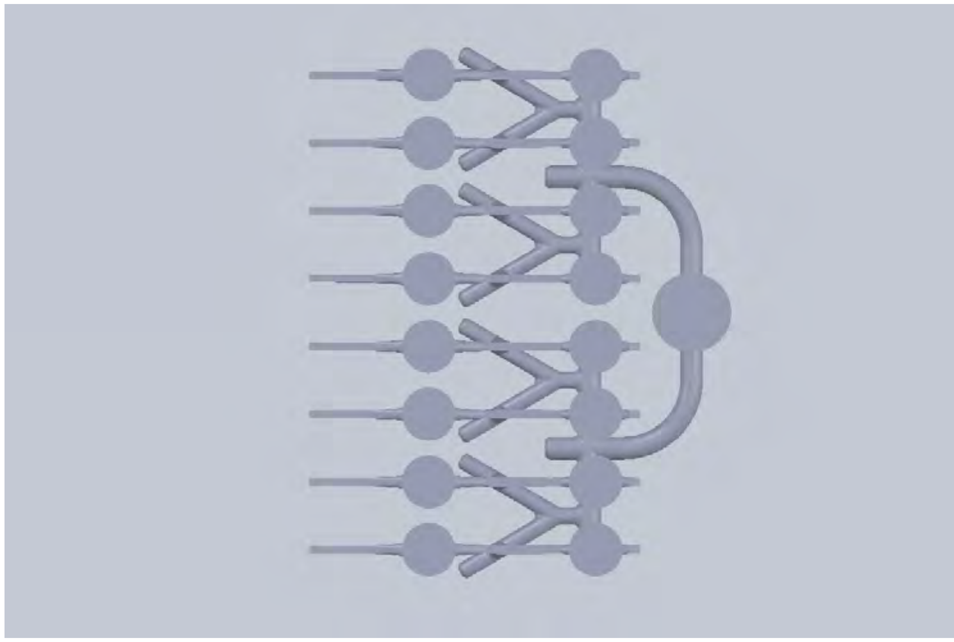

Figure 31. Bottom View of Rigging Design

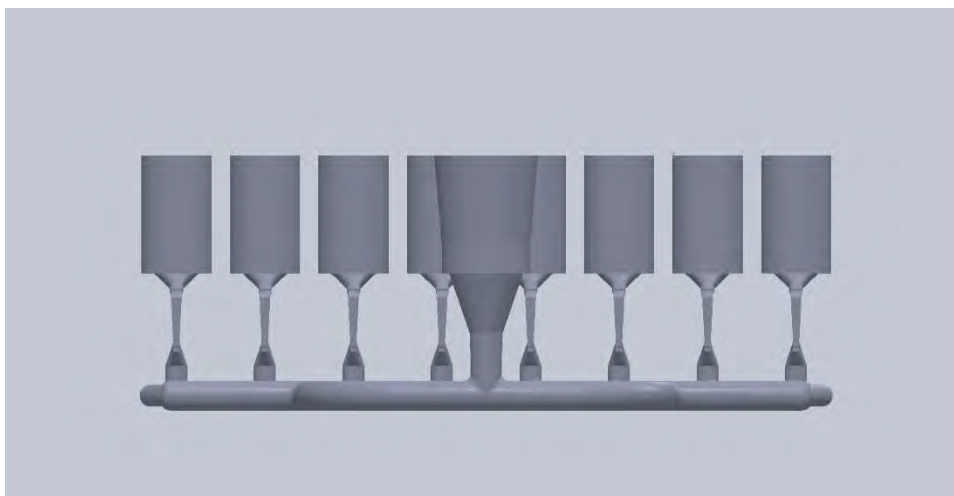

Figure 32. Side View of Rigging Desgin

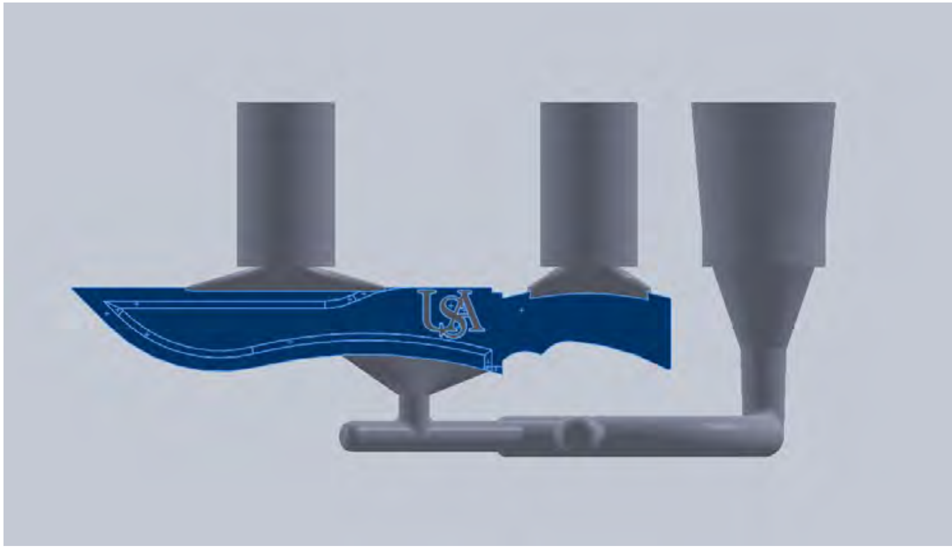

Figure 33. Front View of Rigging Design

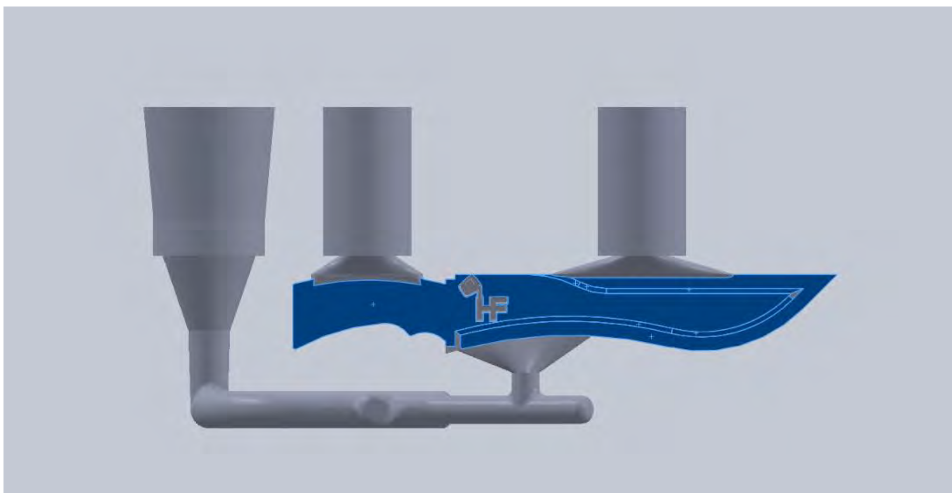

Figure 34. Back View of Rigging Design

Appendix C: Students Working

Figure 35. Team Preparation of Mold 1

Figure 36. Team Preparation of Mold 2

Figure 37. Mold Before Casting

Figure 38. Bowie Knife Before Sharpening 1

Figure 39. Bowie Knife Before Sharpening 2

Appendix D: Rigging Calculations

The following are the calculations for determining the number of risers needed. Refer to Fig. 1 for the dimensions.

- Volume (V) = $Length * Width * Height$
  - Total Length of Knife = 14.25 inches (in)
  - Total Width of Knife = 0.38 inches
  - Total Height of Knife = 2.0 inches

    = $14.25\ in * 0.38\ in * 2.0\ in$

    = $10.83\ in^3$
- Surface Area (SA) = $2[(Length * Width) + (Length * Height) + (Width * Height)]$

  $= 2[(14.25\ in * 0.38\ in) + (14.25\ in * 2.0\ in) + (0.83\ in * 2.0\ in)]$

  $= 69.35\ in^2$
- Modulus of Casting

  = $\frac{Volume}{Surface\ Area}$ = $\frac{7.6}{69.35}$ = 0.156
- Modulus of Riser =

  = $1.2 * \frac{Volume}{Surface\ Area}$

  = $1.2 * 0.156$

  = 0.186
- Cylindrical Riser Diameter: Modulus of Riser = $\frac{Diameter}{4}$

  = $\frac{Diameter}{4}$ = 0.186

  = $Diameter$ = 0.744
- Efficiency

  = $Diameter * 0.8$

  = $0.744 * 0.8$

  = $0.595 \rightarrow 1\ inch\ Diameter\ Riser$
- End Zone

  = $5 * 0.155$

  = $0.755\ in$
- Riser Zone

= $4 * 0.155$

= 0.62 in

- Total Length to Feed = Length - End Zones

= 14.25 - $(2 * 0.755)$

= 12.7 in

- Each Riser Feed Distance

= 1.0 + 0.62 + 0.62

= 2.24 in

- Number of Risers

= $\frac{12.7}{2.24}$ = 5.67 → **6 Risers**

Some modifications will be used to decrease the riser number from 6 to about 2.

- Riser diameter = 1.5 in.
- The contact surface is an oval instead of a circle. The dimensions for the oval are

= $4.425\ in. * 0.4\ in.$

- Area of the Riser Contact Surface

= $\pi r^2 = \pi(0.75)^2$

= 1.77 in^2

- Each Riser Feed Distance

= 4.425 + 0.62 + 0.62

= 5.665 in → 6 in

- Number of Risers

= $\frac{Length}{Feed\ Distance}$ = $\frac{14.256}{6}$

= 2.375 ⟶ ≈ **2 Risers**