

SFSA Cast in Steel – Bowie Knife

Technical Report

Cal Poly SLO Winter & Spring 2020



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Table of Contents

Acknowledgements.....	3
Background.....	6
Bowie Knife.....	6
Students.....	6
Engineering Design.....	6
Blade, Guard & Tang.....	7
Handle.....	8
Material selection and Heat Treat.....	9
Manufacturing.....	10
Bowie Knife.....	11
Handle.....	26
Testing.....	27
Citations.....	28

Table of Figures

Figure 1: American Casting Company Logo.....	3
Figure 2: AWL Tech Logo.....	4
Figure 3: Pacific Heat Treating CO. Logo.....	4
Figure 4: Ridgeline Knife Works Logo.....	5
Figure 5: CAD Render Final Design.....	6
Figure 6: Final Bowie Knife.....	7
Figure 7: CAD model of Handle Design.....	9
Figure 8: Handle Piece plus Hardware.....	9
Figure 9: 420HC Stainless Steel TTT [2].....	10
Figure 10: DFM Casting Model.....	11
Figure 11: Gating design CAD.....	12
Figure 12: Solidification 0.....	12
Figure 13: Solidification 1.....	13
Figure 14: Solidification 2.....	13
Figure 15: Solidification 3.....	14
Figure 16: Fluid Velocity 1.....	14
Figure 17: Fluid Velocity 2.....	15
Figure 18: Shrinkage Porosity 3% Cutoff.....	15
Figure 19: Split Wax Investment.....	16
Figure 20: Joined Wax Investment.....	16
Figure 21: Wax Investment Assembly.....	17
Figure 22: Initial Slurry Coating.....	17

Figure 23: Secondary Slurry Coating	18
Figure 24: Dry Slurry Coating	19
Figure 25: Shell Mold Coatings (in order left to right).....	19
Figure 26: Post Autoclave Mold Shell.....	20
Figure 27: Final Burnout.....	20
Figure 28: Cleaned and Insulated Mold.....	21
Figure 29: Mold Preheating	22
Figure 30: Pouring	22
Figure 31: Knockout	23
Figure 32: Gating Removal.....	23
Figure 33: As-Cast Bowie Knife.....	24
Figure 34: Soft-Jaw Fixture	24
Figure 35: Rough-Ground and Drilled Knives	25
Figure 36: Finishing Grinding 1	25
Figure 37: Finished Grinding 2.....	26
Figure 38: Resin Casting Mold.....	27

ACKNOWLEDGEMENTS



Figure 1: American Casting Company Logo

The team acknowledges American Casting Company for supporting us in the casting process. Cal Poly San Luis Obispo does not have the capability to pour steel on campus. When reached out to, American Casting Company was more than willing to support the team in utilizing their facility and resources as well as guide us in investment casting design decisions. Even through the hard times presented during COVID-19, American Casting Company did not give up. The project would not have been possible without their generous support.



Figure 2: AWL Tech Logo

The team acknowledges AWL Tech for volunteering to provide machining resources necessary to produce the Bowie Knife. The teams design required precision drilled holes to locate the handle assembly. Without access to on-campus machine shops due to COVID-19 this work could not be performed by the team. Even in the economic downturn, AWL Tech made time to help the team out and perform these operations crucial to the team’s success.



Figure 3: Pacific Heat Treating CO. Logo

The team acknowledges Pacific Heat Treating CO. for support with annealing and tempering processes. With limited resources due to college campus closures from COVID-19, the team would not have been able to heat treat the bowie knife otherwise. Pacific Heat Treat generously offered to donate their help, alleviating the financial impact on our sponsor during the hard times of COVID-19.



Figure 4: Ridgeline Knife Works Logo

The team acknowledges Ridgeline Knife Works. The team was faced with a challenge when COVID-19 restricted access to resources available at Cal Poly San Luis Obispo, such as: CNC and manual mills, drill press, and grinding equipment. Ridgeline Knife Works generously offered to perform grinding operations to allow the team to finish the bowie knife. This amazing help kept the team in the competition and put the finishing touches on the beautiful knife.

The team acknowledges Dr. Dan Walsh for consulting on material science and heat treat recommendations. Dr. Walsh volunteered to consult the team on the different material property affects presented by the different heating and cooling rates the knife will be subjected to.

The team acknowledges Paul Bos Heat Treating for volunteering their time to consult the team on heat treat conditions to best achieve the teams desired material property goals. Paul Bos Heat Treating fielded a phone call from the team and without any ask for compensation, helped the team by sharing their acquired knowledge on knife specific heat treat.

The team acknowledges Steel Founders Society of America (SFSA), and specifically Kimberley Schumacher, for organizing the competition. Without SFSA and Kimberly the team would not have had this amazing experience.

In all, the team expresses extreme gratitude to these great companies and individuals who supported the team throughout the project. The team recognizes the sacrifice these companies made is extraordinary because of the financial and logistical hardship presented to all during COVID-19.

BACKGROUND

Bowie Knife

The Bowie knife popularity and origin stem from the famous Sandbar fight in 1827. James Bowie famously used his original Bowie knife described to have a “butcher knife” profile [1]. The Bowie Knife style became popular for hunting and work applications. The style of the knife has changed overtime, starting out with a “thick, heavy butcher-knife-like blade”. The design has changed involving many different renditions, often featuring a sharp back on the tip and newer designs of the handle for increased function, usability, and durability.

Students

Jack Maughan, Gerrit Sperling, and Parker Duncan are representing California Polytechnic State University San Luis Obispo (Cal Poly SLO) in the Steel Founders Society of America (SFGSA) Cast in Steel competition. The team is active in both local chapters of American Foundry Society and Society of Manufacturing Engineers. Jack, Gerrit and Parker are currently 4th year manufacturing engineering students at Cal Poly SLO.

ENGINEERING DESIGN

The team wanted to incorporate aspects of the old design with standard new features of the bowie knife for the overall aesthetic design. This rendered a Bowie knife with a thick, meaty blade and a sleek modern ergonomic and comfortable handle.

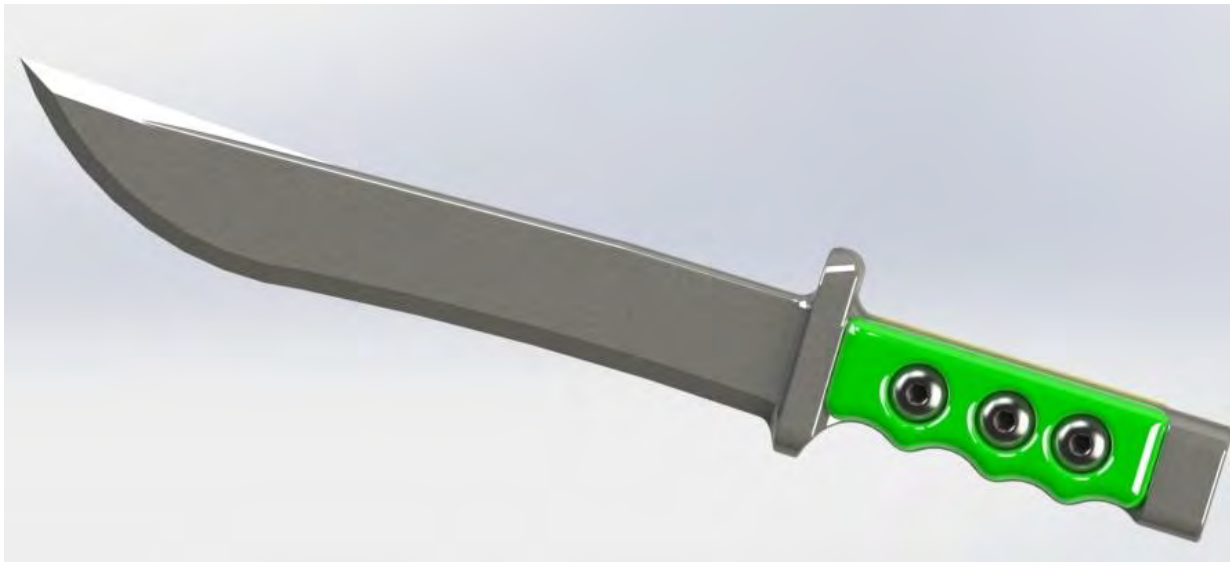


Figure 5: CAD Render Final Design



Figure 6: Final Bowie Knife

Blade, Guard & Tang

The general shape of the final metal cast Bowie knife can be seen in Figure 5. The team designed this custom geometry using SOLIDWORKS CAD by Dassault Systems.

The design process started with hand drawings to develop to the overall desired shape of the blade. These ideas were translated into a sketch outline and then transformed into a solid body. The design intent had three main goals: knife function, DFM for casting, and a beautiful aesthetic to commemorate traditional and modern Bowie knives.

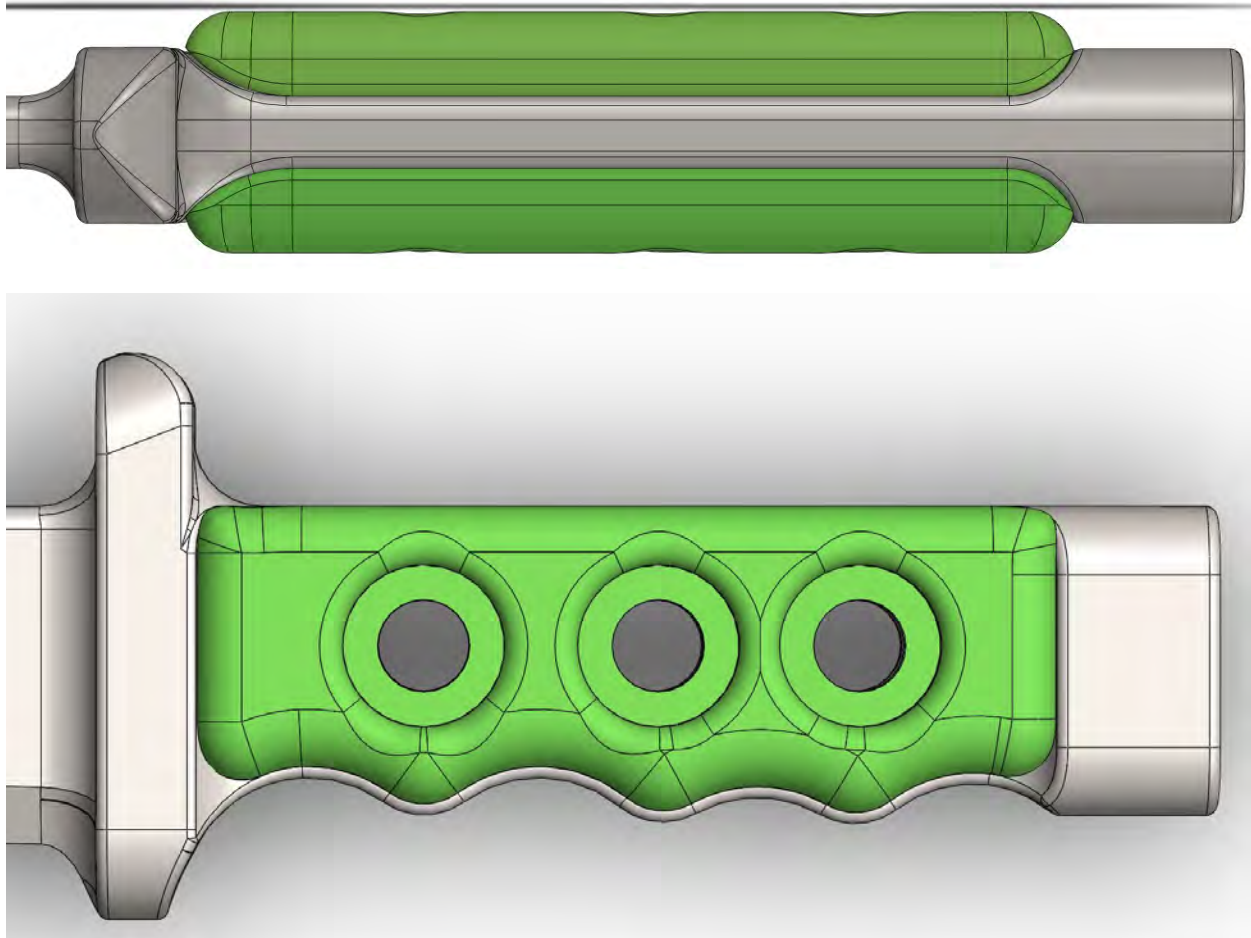
To achieve the goal of knife function, the team focused on making a hard, durable, and ergonomic knife. The hardness is achieved through material selection and heat treatment, outlined in Material selection and Heat Treat. The intended uses of the knife will submit it to high loads and impacts. The design eliminates any unnecessary sharps to reduce maximum stresses during use. Generous fillets have been utilized where the blade meets the guard to eliminate chances of failure at the high stress zone during impacts or use for non-impactful cutting or prying. The team focused on developing an ergonomic design as well. This is seen in the portion of the knife tang, intended to fit the grip of the user's hand. The shape was derived from measurements of the hand and testing with rapid prototyping to make a comfortable contour to grab. This is further detailed in Handle on page 8.

The DFM for casting went hand in hand with designing to reduce stress concentrations. The team designed a uniform knife body with generous rounds. This geometry helped immensely in improving material flow, easing the manufacturing of the ceramic shell, and reducing micro porosity due to steady flow and inside-out cooling. The manufacturing process is detailed further in Manufacturing.

Handle

The goal of the handle was for comfort and utility. The material choice was a resin casted polymer. The polymer allows for a durable and comfortable to hold handle. The handle is designed to be a two-piece system to clamp to the knife using coated steel binder barrels.

The handle design starts with the ergonomic profile of the cast knife handle portion. This profile was designed to fit with an average hands palm width and finger grip. The Polymer handle adds thickness and a soft easy to grip surface, while following this hand shaped profile of the knife. CAD modeling of the knife-handle assembly is shown in Figure 7, and a close-up image of one piece of the handle and the hardware is seen in Figure 8.



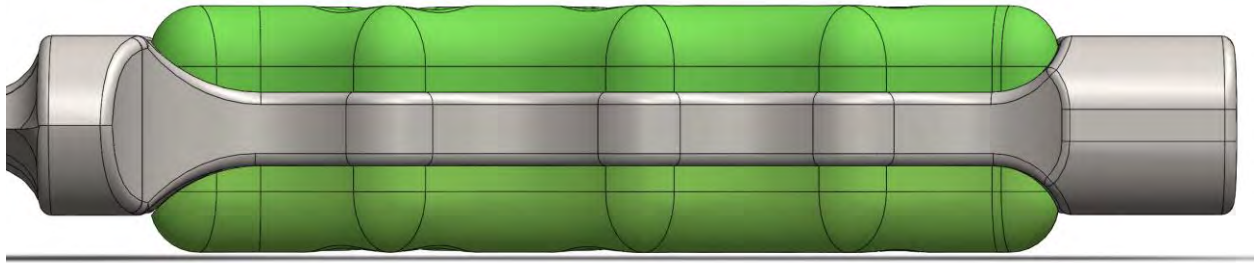


Figure 7: CAD model of Handle Design



Figure 8: Handle Piece plus Hardware

MATERIAL SELECTION AND HEAT TREAT

The team chose 420HC Stainless Steel for the knife. This material is popular among large knife manufacturing and has desirable levels of hardness achievable through heat treat processes. The team wanted a Bowie knife with maximum hardness and blade edge retention, while maintaining toughness to resist fracture when used for striking applications. The team performed research by referencing 420HC Stainless Steel data sheets and consulting with materials science and heat treat experts. The team created a preliminary plan for heat treat outlined in sequential steps below:

1. Annealing
 - a. Heat up to 1600°F at 200°F intervals with 30-minute soak at each interval
 - b. Turn furnace off and let cool to 600F or lower if possible
2. Quench
 - a. Atmospheric furnace to 1950°F (slightly higher austenitizing temperature)
 - b. Quench
 - i. with nitrogen gas (58-59)RC
 - ii. with oil

- c. Cryogenic treatment (60-61)RC
 - i. Possible warpage
 - d. Alternative option: local heat-treat of just the blade or carburizing
3. Tempering
- a. 450°F Tempering after cryogenic
 - b. 350°F if else

This outline details different options for annealing, quenching, and tempering analyzed by the team. The anneal process was just one option and was followed with slight alteration to the incremented heating to speed the process. The team chose a nitrogen quench to attempt and achieve an RC 58 or 59 hardness. The cryogenic treatment was not used to avoid possibilities in warpage or creating a knife which would be too hard and would not perform as well under impact from striking. This hardness is comparable to popular knife manufacturer Buck Knives hardness on their professional grade knives.

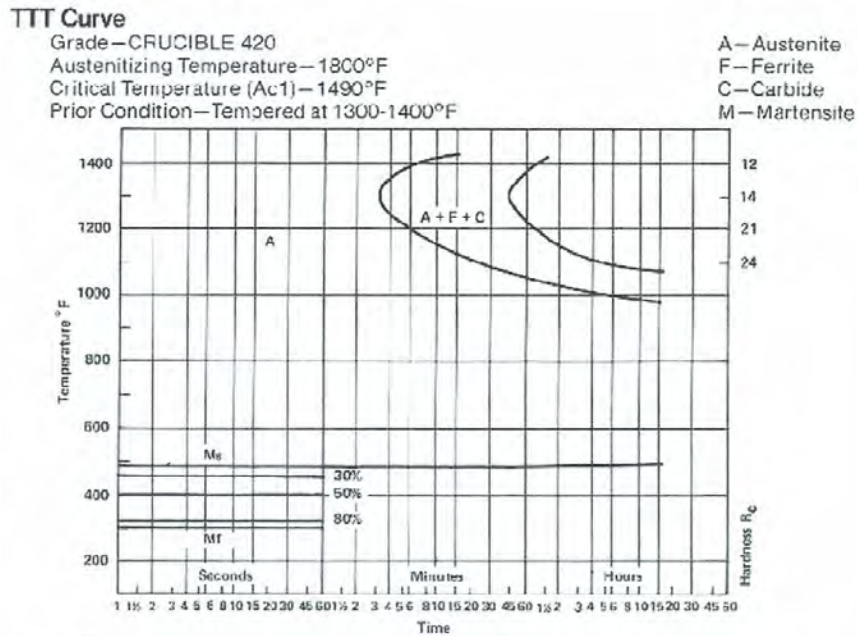


Figure 9: 420HC Stainless Steel TTT [2]

The heat treat process is a crucial step because after the casting process, the knife is expected to be very martensitic based on the TTT curve shown in Figure 9. This would lead to a brittle knife which would not meet the team’s toughness expectations for the knife.

MANUFACTURING

The team manufactured the knife by working with many different companies, referenced in Acknowledgements, to complete manufacturing processes which were not achievable with campus resources at Cal Poly SLO, or not achievable because of restricted access to tools and machines due to COVID-19. The team used SOLIDWORKS to prepare all CAD models necessary for manufacturing.

Bowie Knife

The knife blade, guard, and tang are manufactured as one casting. The casting process chosen is investment casting. Investment casting allows for the desirable surface finish, rapid tooling, and ability to manufacture the level of geometric complexity required for the Bowie knife design.

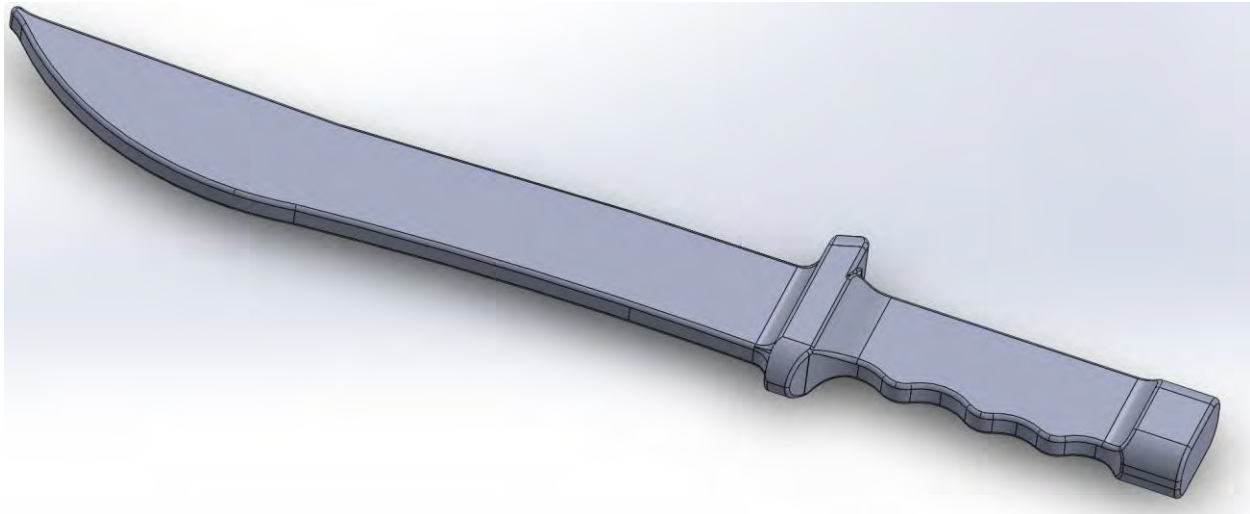
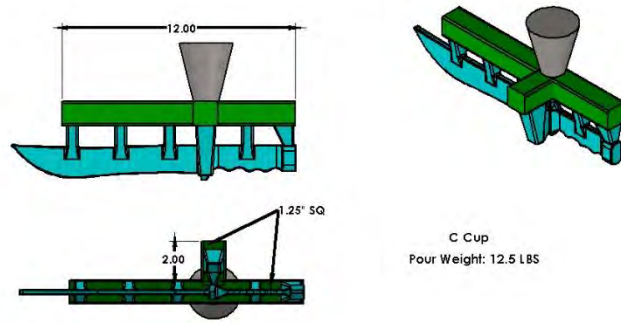


Figure 10: DFM Casting Model

To create a manufacturable design for the Bowie knife, the team modified multiple geometries on the model of the finished knife, shown in Figure 5. The team focused on eliminating sharp corners and edges to encourage desirable molten metal flow in the mold. The team worked to keep all sections of the casting as uniform as possible to encourage these desirable flow properties. The team kept a minimum radius for all corners and edges of greater than 0.03” at the recommendation of American Casting Company, to prevent any issues with filling the mold cavity. These DFM features can be seen in Figure 10.

The next step of the manufacturing design process was to design a gating system to optimize material flow into the mold cavity and eliminate any chances of porosity, micro shrinkage, or other defects. These features will all be a part of the wax investment to make the ceramic mold shell. American Casting Company has access to two crucial technologies which helped with the design of the investment and gating: a high accuracy wax 3D printer and casting solidification and flow simulation software from proCAST.

Casting solidification and flow software helped aid the gating process by identifying gates causing unwanted solidification or turbulent flow. The casting is oriented with the blade portion down in order to put the most critical feature, the blade, in position to have the best fill because gravity will push the material in the downward direction. The goal from there was to establish uniform cooling from the bottom up and have no portions of the gating cool quicker than in the body of the knife. The CAD design of the gating is shown in Figure 11.



C. Cup
Pour Weight: 12.5 LBS

Figure 11: Gating design CAD

Using this simulation revealed the need for another gate to feed into the guard, the thickest portion of the casting, to feed more material and prevent any solidification in the gates before solidification of this large section. This solidification analysis can be seen sequentially in Figure 12, Figure 13, Figure 14, and Figure 15. Figure 13 shows how solidification occurs first in the knife part and then in the gates. Figure 14 and Figure 15 show this specifically for the slowest cooling portion, the guard.

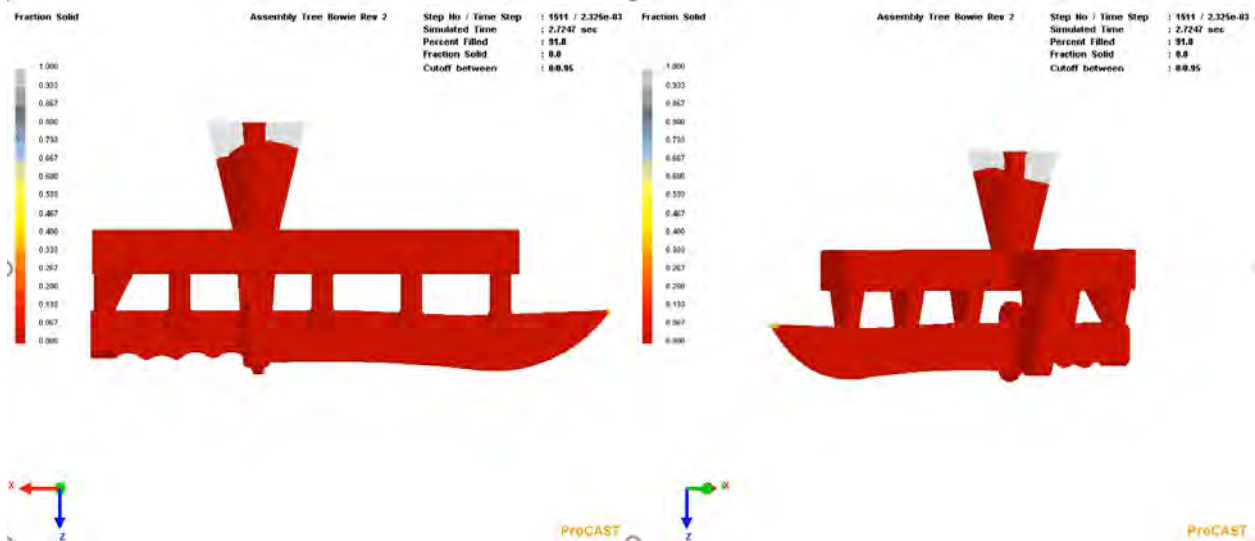


Figure 12: Solidification 0

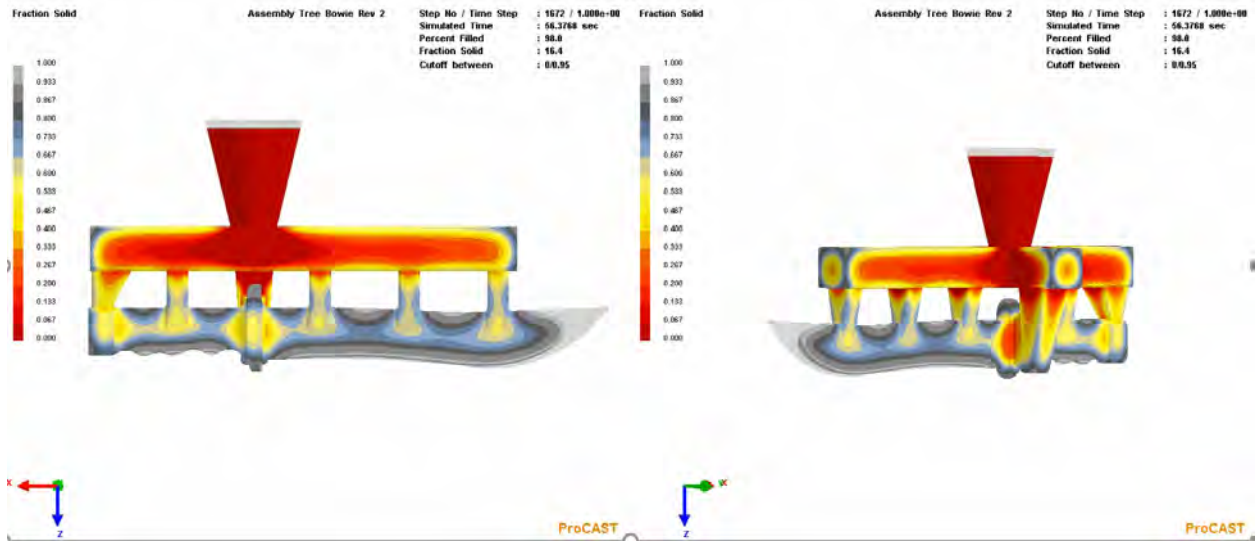


Figure 13: Solidification 1

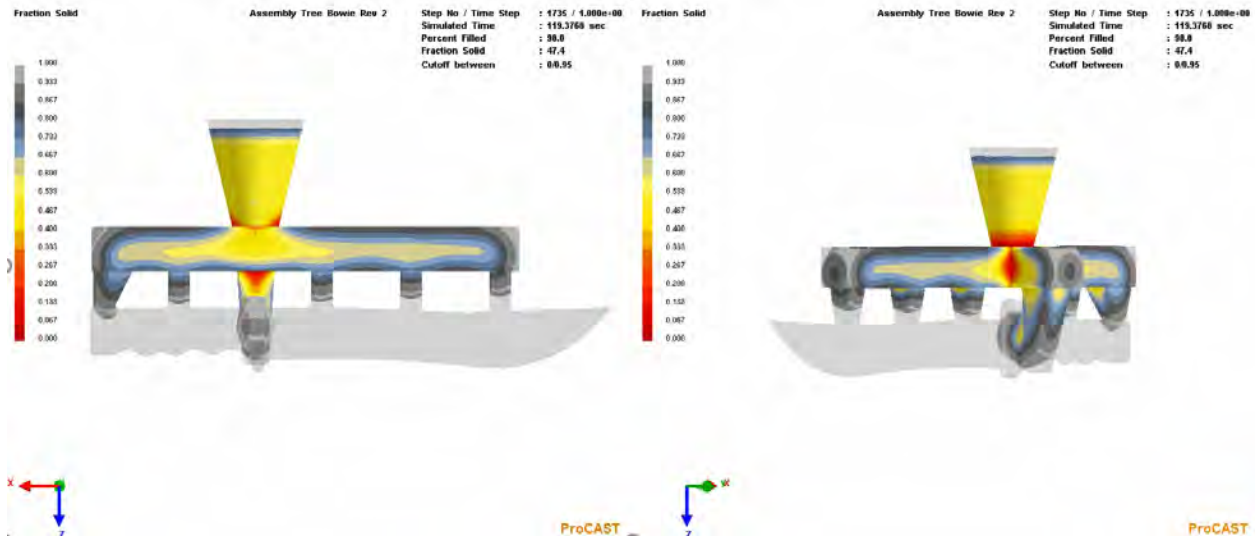


Figure 14: Solidification 2

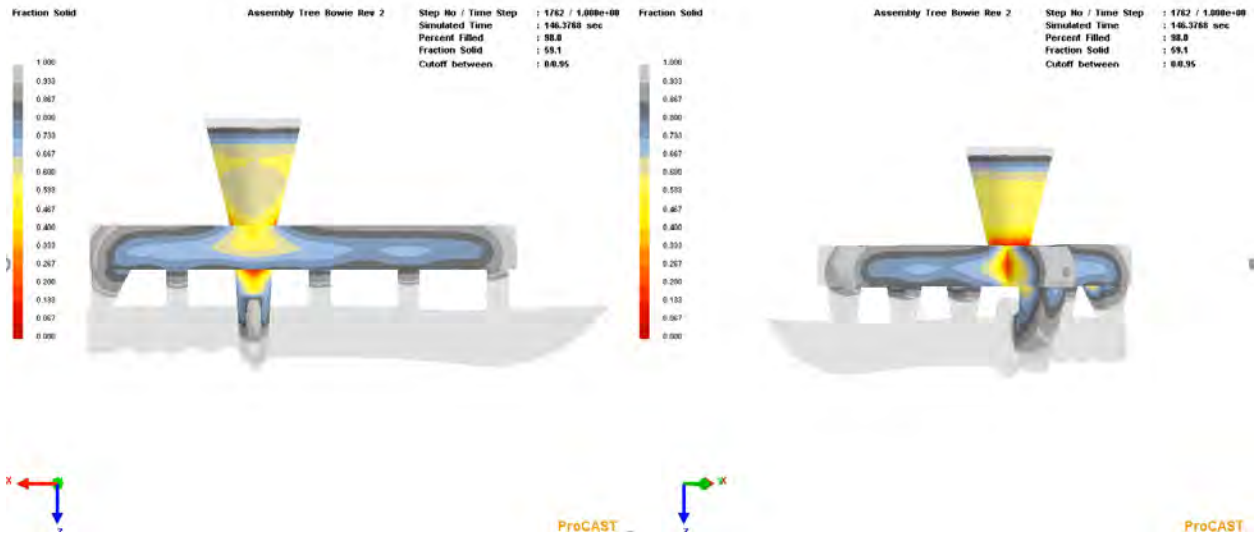


Figure 15: Solidification 3

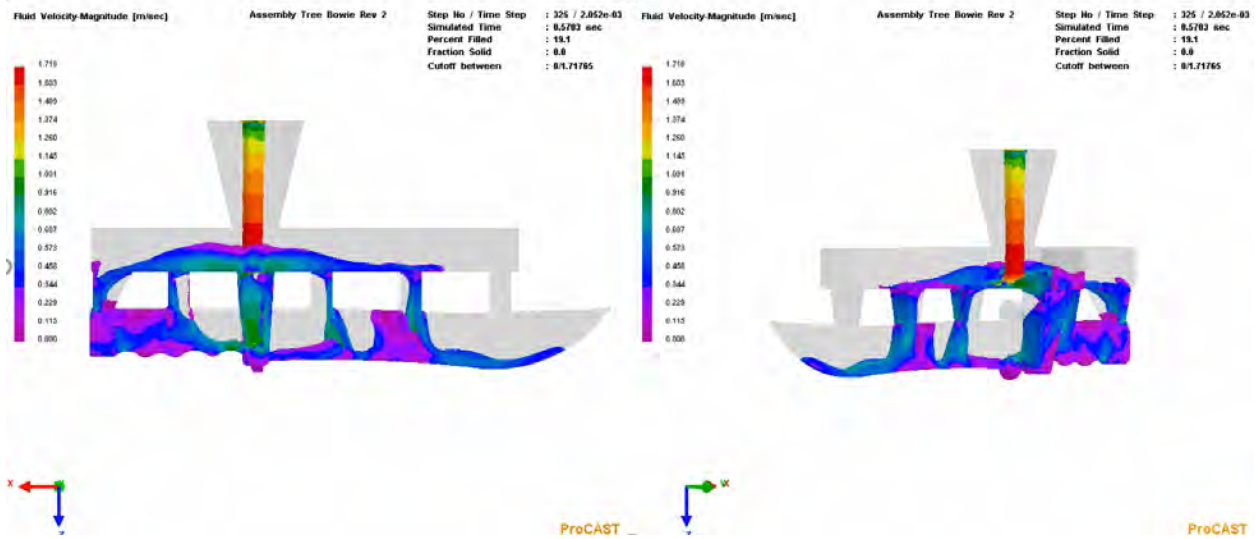


Figure 16: Fluid Velocity 1

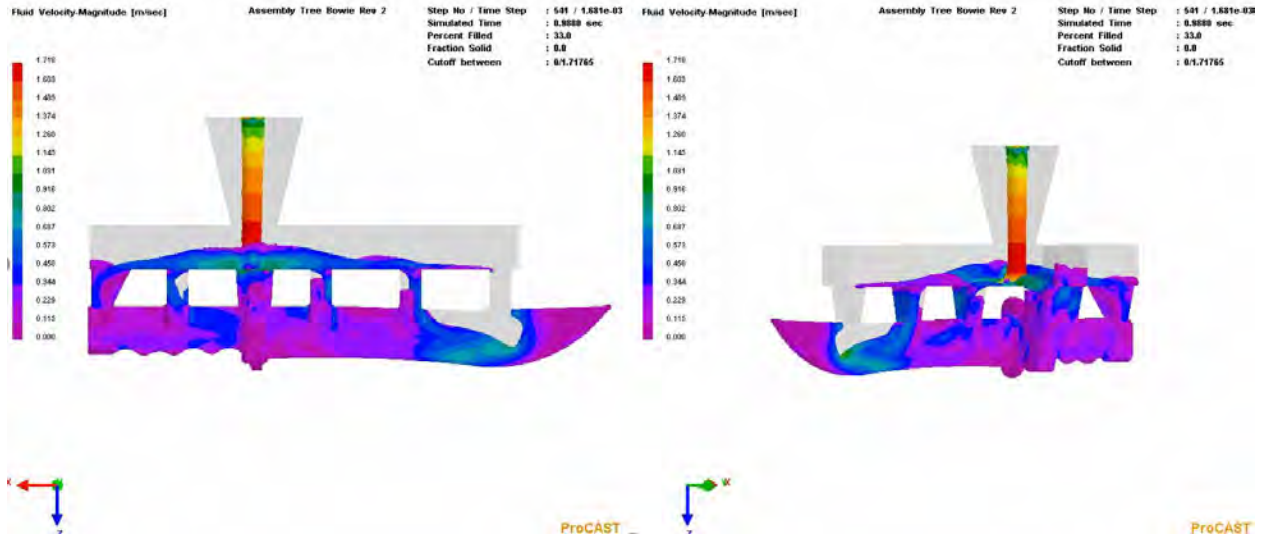


Figure 17: Fluid Velocity 2

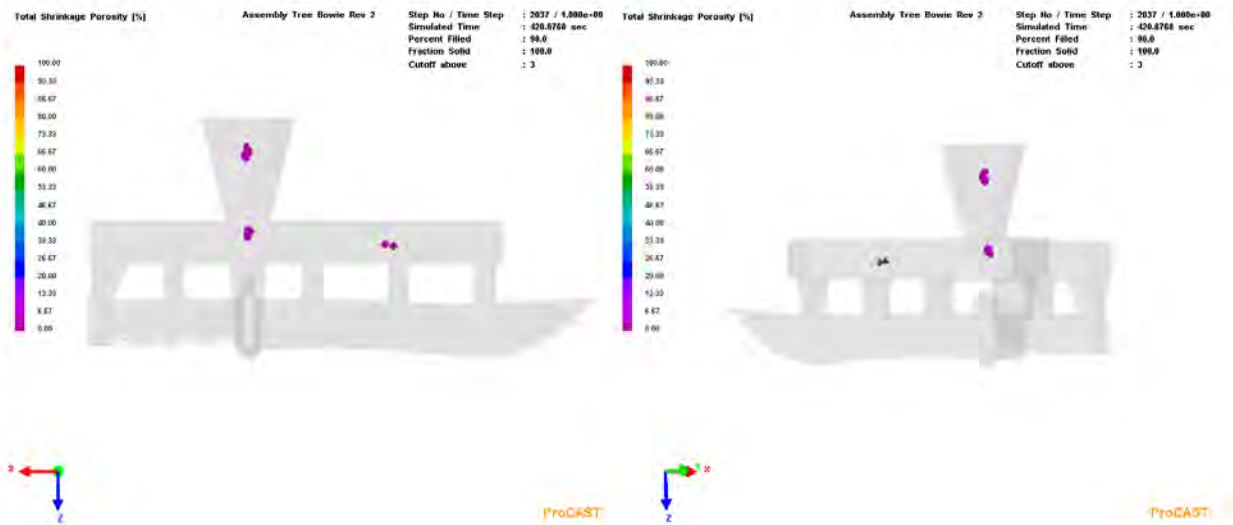


Figure 18: Shrinkage Porosity 3% Cutoff

The flow analysis was used to monitor any extra high velocities of the material which could lead to defects. Figure 16 and Figure 17 show the flow progression and relatively even filling of the mold cavity. Another concern relieved through simulation was any material beginning solidification before the cavity finished filling. Figure 12 shows how the mold cavity, gating, and runners will fill with material before any solidification begins. Note the red color indicates no solidification and grey color indicates a fraction solid of 1 (1 being completely solidified). Also, shown in Figure 18, is analysis for porosity due to shrinkage. The purple dots indicate possibilities of this, the model shows no significance of this in the main body of the part.

The wax 3D printer allowed for rapid production of the investment tooling required for this low volume custom job. This eliminated the need of any extra tooling such as a traditional injection molding tooling to create an investment which increases the complexity of the process and cost. Due to the large size of the Bowie knife design, the geometry exceeded the maximum volume

envelope of the 3D printing machine. The workaround for this was to print the investment in two pieces and then join the wax pieces together. This process is shown in Figure 19 and Figure 20.

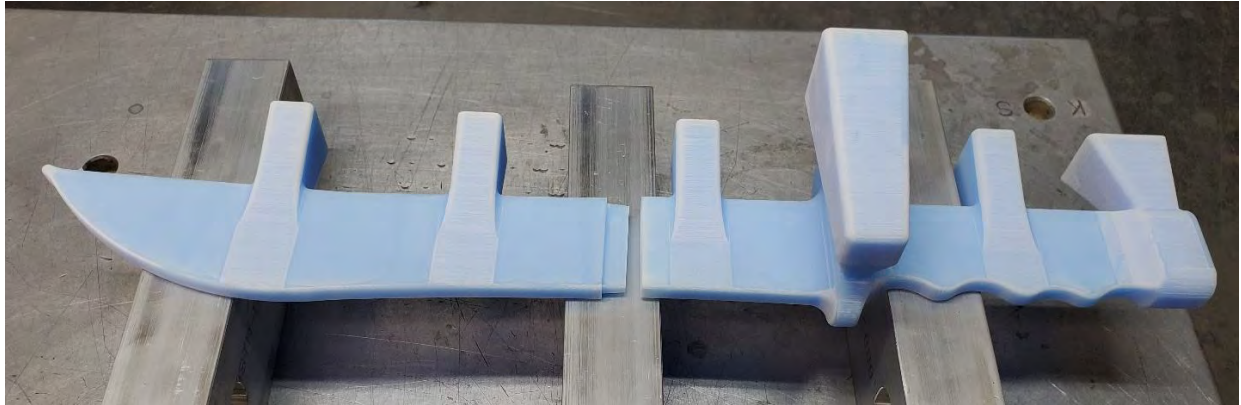


Figure 19: Split Wax Investment

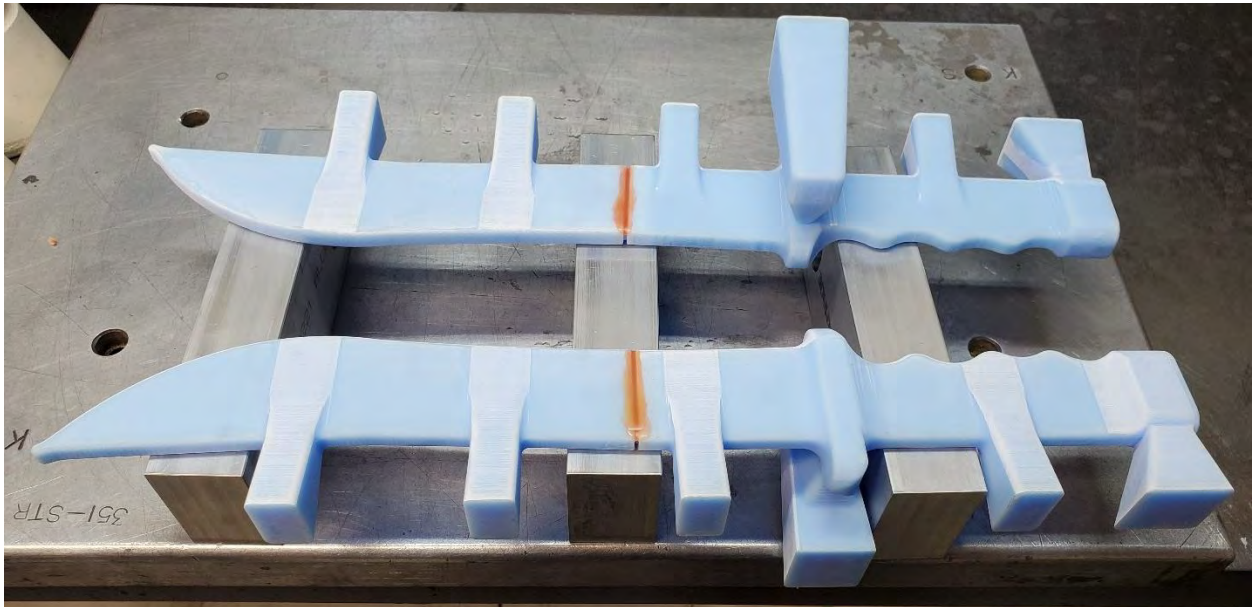


Figure 20: Joined Wax Investment

The wax patterns then needed to be assembled to a standard wax runner geometry and pouring cup. The process final investment assembly is shown in Figure 21.

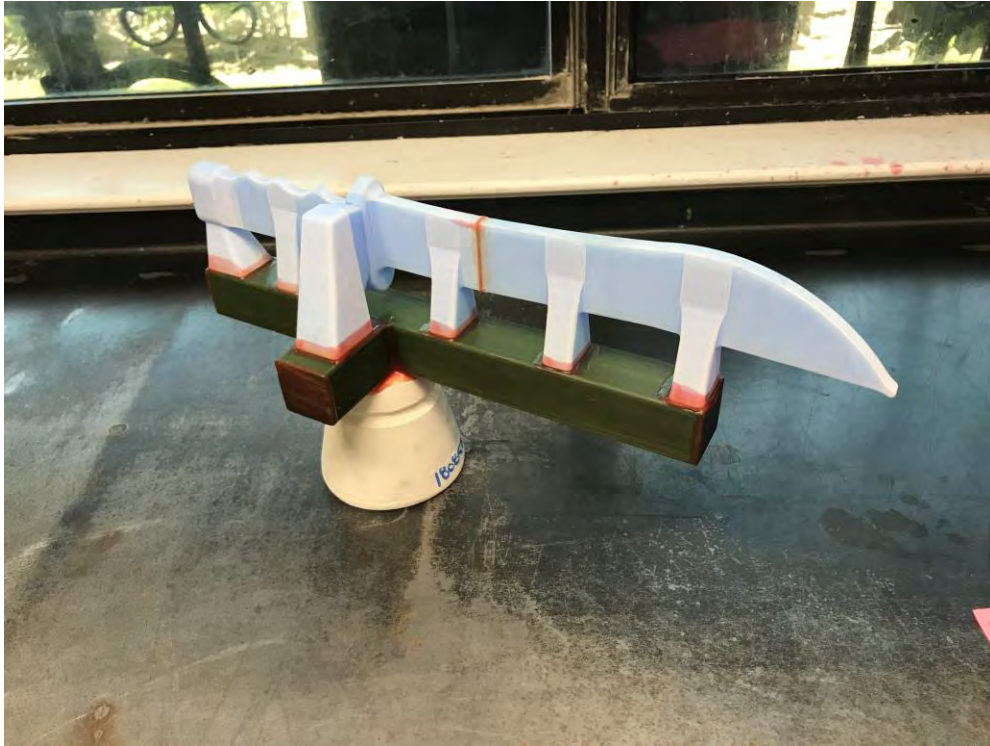


Figure 21: Wax Investment Assembly

The investments were then cycled through numerous slurry coatings to achieve a final mold shell. The coating processes are visible in detailed order through Figure 22, Figure 23, Figure 24, and Figure 25.



Figure 22: Initial Slurry Coating



Figure 23: Secondary Slurry Coating



Figure 24: Dry Slurry Coating



Figure 25: Shell Mold Coatings (in order left to right)

Next, the dewax and burn out process began using American Casting Company's autoclave. Figure 26 shows the mold shell after the wax had been burned out in the autoclave and Figure 27 shows the process of the final burnout occurring.

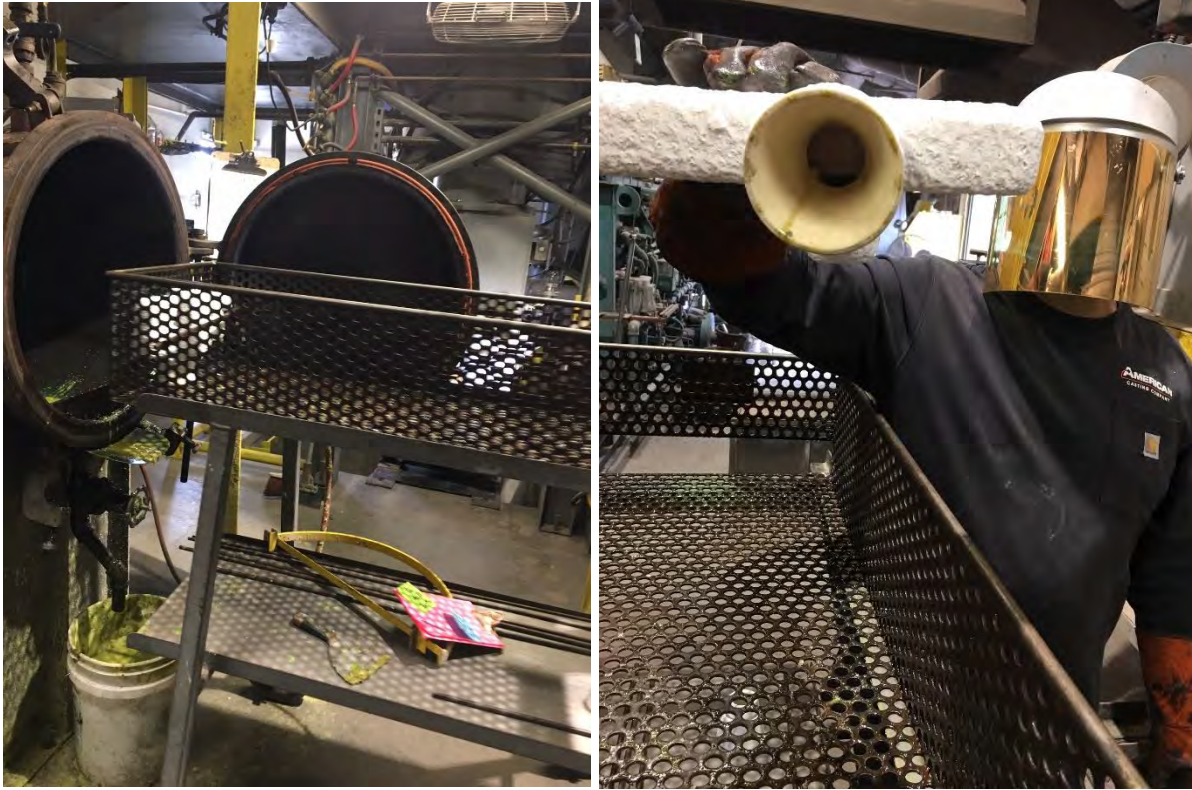


Figure 26: Post Autoclave Mold Shell



Figure 27: Final Burnout

Next, the molds were cleaned and wrapped with insulation to slow the cooling process to hit targeted solidification timing, shown in Figure 28. After a trial pour, chromium pitting was found in the knife. This was likely due to an improper solidification rate. The insulation was removed, and the pour temperature was dropped from 2850°F to 2800°F to solve this issue successfully.



Figure 28: Cleaned and Insulated Mold

The molds were then ready for pre-heat and pouring, Shown in Figure 29 and Figure 30. The ingot 420HC Stainless Steel alloy was melted with induction heating. The pouring process was performed by hand at American Casting Company. The temperature poured was 2800°F as previously noted.



Figure 29: Mold Preheating



Figure 30: Pouring

After pouring, knockout was performed to remove the casted knife and gating from the mold, as visible in Figure 31. Figure 33 shows the cast Bowie knife with the gating removed. After post-process and gating removal, the final as-cast knife can be seen in Figure 33.



Figure 31: Knockout



Figure 32: Gating Removal



Figure 33: As-Cast Bowie Knife

The as-cast knife was initially beveled with rough grinding processes and then sent off to AWL Tech for machining of the holes for the handle. A soft jaw vise fixture was used to grip the handle of the knife to complete the drilling operations as seen in Figure 34. It was necessary to perform an annealing process on the knives to complete the drilling operations without breaking tooling. The rough ground and drilled knives are shown in Figure 35, ready for finishing grinding and heat treatment.



Figure 34: Soft-Jaw Fixture



Figure 35: Rough-Ground and Drilled Knives

The final steps of the manufacturing process were heat treatment and finish grinding. The rough ground blades were sent to Pacific Heat Treat CO. for final heat treat according to the desired specifications outlined in the Material selection and Heat Treat section. A 59 RC minimum specification was desired from the final heat-treating process.



Figure 36: Finishing Grinding 1



Figure 37: Finished Grinding 2

To finish grinding the blades, some creative freedom was given to Ridgeline Knife Works on the targeted blade angle in order to successfully grind the blades. Figure 36 shows a snapshot of how the final grinding processes were performed, and the finished, ground blades can be seen in Figure 37. The finished and assembled Bowie knife can be seen in Figure 6.

Handle

The handle was designed with DFM for casting similar to the Bowie knife. The team had limited options for handle manufacturing because of restricted access to the Cal Poly SLO laboratories and machine shops. However, the team wanted to produce this component with no help from outside sponsors to amplify the teams hands-on work on the project. With access to a Creality Ender 3 FDM printer, the team designed a handle to be molded through resin casting.

The manufacturing design focused on continuous sections and eliminating sharp corners and edges to allow for a good gravity fill of the mold cavity. The design had to consider the limitations of geometric complexity presented by the rather low-end 3D printer creating the molds. Initially designs with coring were used to create the counterbore hole features. These cores broke off in the part when separating the mold and could not be removed without damage to the part. This led the design to eliminate these smaller cores, and instead drill holes in the final handle.

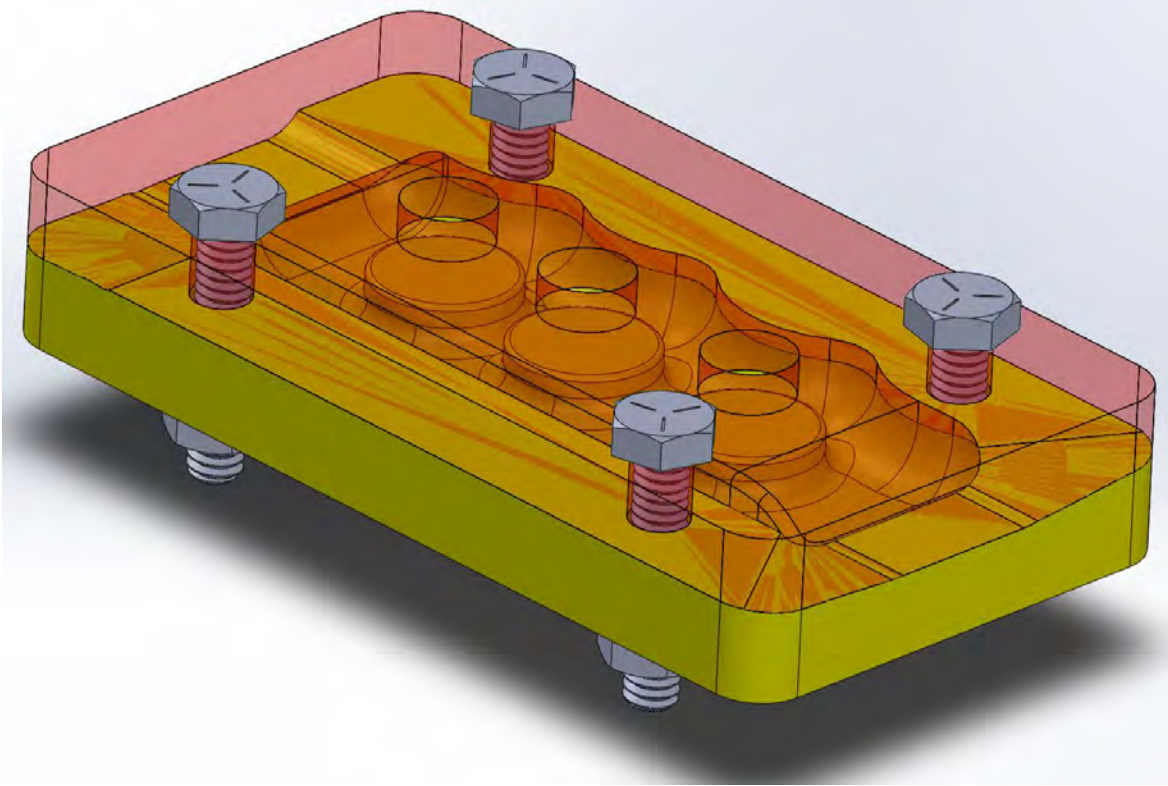


Figure 38: Resin Casting Mold

The mold used is shown in Figure 38. The top red piece is shown transparent for visibility of the mold cavity. The initial design had just one hole in the middle of the top piece to be used as the sprue. With only the one hole on the top piece the cavity was not filling all the way, there were gaps left at both ends of the handle. To address this issue, two more holes were added as seen in Figure 38. These holes were implemented to be risers to encourage complete filling of the cavity. These holes were selectively located over the section of the handle where the team planned to drill holes for the handle hardware. The holes were sized to the drill diameter and the mold was utilized as a drilling fixture as well. The handles were drilled with a standard size, $7/16''$ to allow for both clearance of the $3/8''$ binder barrel hardware and extra positional tolerance for the location and size of the hole pattern and the holes themselves. This generous clearance hole was deemed necessary because the team was using a hand-held power drill since the team could not access Cal Poly SLO campus resources that allow for these operations to be performed with more accurate tools and machines.

TESTING

Testing for the knife could only consist of non-destructive tests due to the limited quantity of final products the team was able to produce. The tests performed were a Rockwell hardness test, handle assembly GO/NOGO, and visual inspection for defects. The final knife is RC57 hardness, slightly under the team's goal, however surely hard enough to thrive during cutting operations. The handle assembly did not face any issues with assembly, the $3/8''$ binder barrel hardware was used as a GO/NOGO to ensure the handle and knife holes were sized and located to achieve a

proper fit. The knives passed all visual inspection after cleaning away any leftover dye or debris from processing.

Physical tests for utility of the knife will be performed at the SFSA Cast in Steel Competition in July of 2020. The results will be available through SFSA.

CITATIONS

[1] *Handbook of Texas Online*, William R. Williamson, "BOWIE KNIFE," accessed June 02, 2020, <http://www.tshaonline.org/handbook/online/articles/lnb01>.
Uploaded on June 12, 2010. Modified on July 12, 2017. Published by the Texas State Historical Association.

[2] *Crucible Industries LLC*, "Crucible Data Sheet," Issue #7, 575 State Fair BLVD., Solvay, NY 13209