

Cast in Steel 2020

Bowie Knife Final Report



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Department of Materials
Science and Engineering



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Team Members

Bianca Avila - I am a Senior MSEN student at Texas A&M and I hope to be a future metallurgist! Whoop!



Nathaniel Lies - I am a Senior MSEN student at Texas A&M and I am the project lead for this competition! Whoop!



Garrett Smola- I am a Senior MSEN student at Texas A&M and I had fun modeling the bowie knife for this competition! Whoop!



Tafimul Tasif - I am a Senior MSEN student at Texas A&M. I helped research the casting process for the bowie knife! Whoop!



Greg Wong - I am a Senior majoring in MSEN at Texas A&M and I Produced the video and did research for the knife! Whoop!



Abstract

For the 2020 Cast in Steel competition, our team was tasked with designing and producing a bowie knife. The bowie knife is a fairly large knife said to be designed by Jim Bowie, an important figure in the Battle of the Alamo. Wishing to honor Jim Bowie and the Alamo, we decided that the theme of this knife would be centered around Texas and, more specifically, the Alamo. The design of the blade, guard, and tang was made in Solidworks, measuring close to 20 inches in total. From a wide variety of steels, we decided on D2 tool steel. With D2 steel's excellent hardness, toughness, and wear resistance, D2 steel is ideal for our bowie knife. In regard to casting, we decided that the investment casting technique would be ideal in our case due to the high fidelity of the casts. With the help of 3D systems, a pattern for ten blades made of photopolymer was 3D printed. From this pattern, a ceramic shell was made by dipping the pattern in a ceramic slurry and melting out the polymer from the shell. With the help of TexCast, molten D2 steel was poured into the shell, making a cast of ten knives. From these ten knives, we picked the best one to continue through the process to heat treatment. After heat treatment, the knife was ground and polished. From there, we made a handle out of spalted pecan, then laser etched, and sharpened the knife.

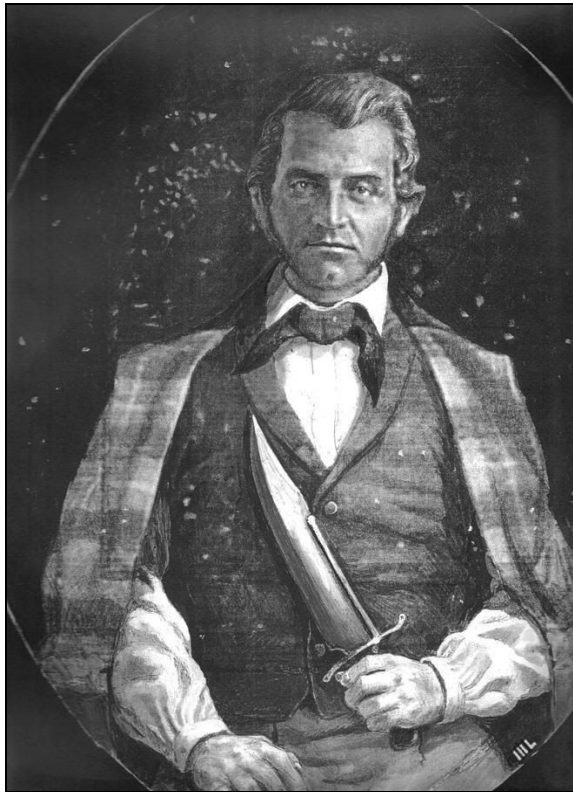


Figure 1. Historical painting of James Bowie with a bowie knife.

Introduction

In this project, a bowie knife was designed and manufactured with specifications given by the Steel Founders' Society of America (SFSA) for their Cast in Steel competition. The Cast in Steel competition allows for college students to apply their knowledge of computer modeling, alloy development and selection, additive manufacturing, and casting techniques to make a complete product.^[1]

There are three main specifications about the design of the knife that were given to us by the SFSA. First, the blade of the bowie knife needed to have a length between 9 and 14 inches. Second, the blade of the bowie knife needed to be integrally cast with the tang and the guard. Third, the finished product must have traits, historically proven, that would qualify it as a bowie knife.

The anatomy of a knife is shown in Figure 2 and will become important when discussing the design of our bowie knife.

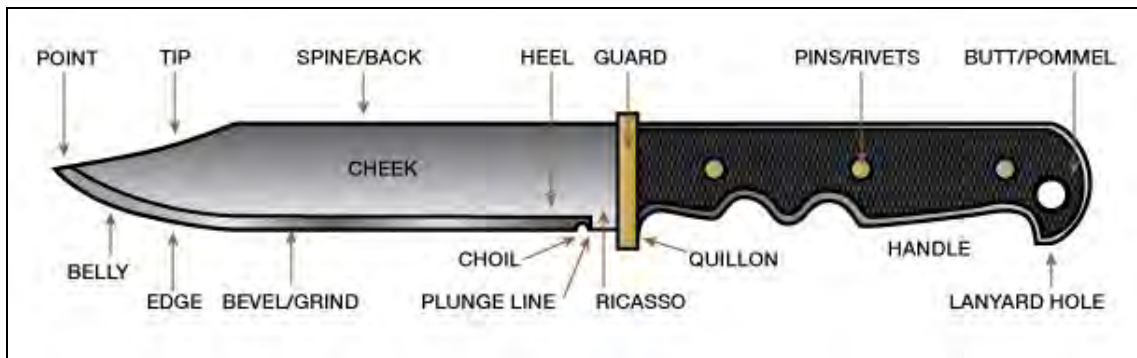


Figure 2. The anatomy of a fixed blade knife^[2]

Historical Background

Throughout the Bowie knife's history, it has gone through many iterations. The first Bowie knife was made by Rezin P. Bowie and was given to James (Jim) Bowie for protection. This first iteration resembled a large butcher knife with a thin blade and no guard.^[3] A recreation of this type of bowie knife is shown in Figure 3. This knife gained popularity when James Bowie killed Norris Wright with one stab in the Sandbar Fight along the Mississippi River on September 19, 1827.^[3,4]



Figure 3. Interactive display from “Bowie: Man-Knife-Legend” shown at the Alamo. Shows an early example of a bowie knife^[5]

After this incident, the Bowie knife started to be seen as a reliable backup weapon to firearms. With this influx of popularity and a push from Rezin Bowie, the bowie knife became a fad across the states. In 1830, James Black, an Arkansas blacksmith, made a knife for James Bowie with a sharpened curved top edge. A knife made in this style is shown in Figure 4. James Bowie went to live for another 6 years before losing his life in the Battle of the Alamo on March 6, 1836, becoming an Alamo hero.^[3,4,6]



Figure 4. The Carrigan, a knife made by James Black, on display in the Historic Arkansas Museum^[7]

In modern times, the Bowie knife has a much different design than the ones shown above. These knives are usually distinguished by their large size, a cross-guard, and a clip-point.^[3] A good example of a modern day style Bowie knife can be seen in Figure 5.



Figure 5. A modern day example of a Bowie knife produced by Winchester^[8]

Knife Design

For our theme, we designed the bowie knife to be recognizable by modern standards, but still harken to James Bowie and the Alamo. Since the bowie knife is known for being a large knife, we decided to make the length and width of the blade be 13.5 in. and 0.25 in., respectively. As it can be seen in Figure 5, the tips of modern day bowie knives look as though the knife was clipped, this is called a clip point. To follow this distinguishable trend, we decided that our knife would have a clip point. For the guard, we decided between three different types: classic guard, s-guard, and u-guard. We 3D modeled each of these guards to see which one would suit our vision the best. For the tang and handle, we decided to go with a full tang design to give us a rustic feel and good structural support for the knife. We decided that the handle would be made out of a hard wood, preferably one native to Texas.

3D Modeling of the Blade

Using Solidworks, we initially designed three different knives, corresponding to the three guard types discussed in the knife design section. An isometric view of these models can be seen in Figure 6. After reviewing these models, we chose the classic guard model because it fit better with our Alamo theme. After deciding on a guard, a full assembly of the classic-guard knife was made to better envision what the final product would look like. This is shown in Figure 6 (d).

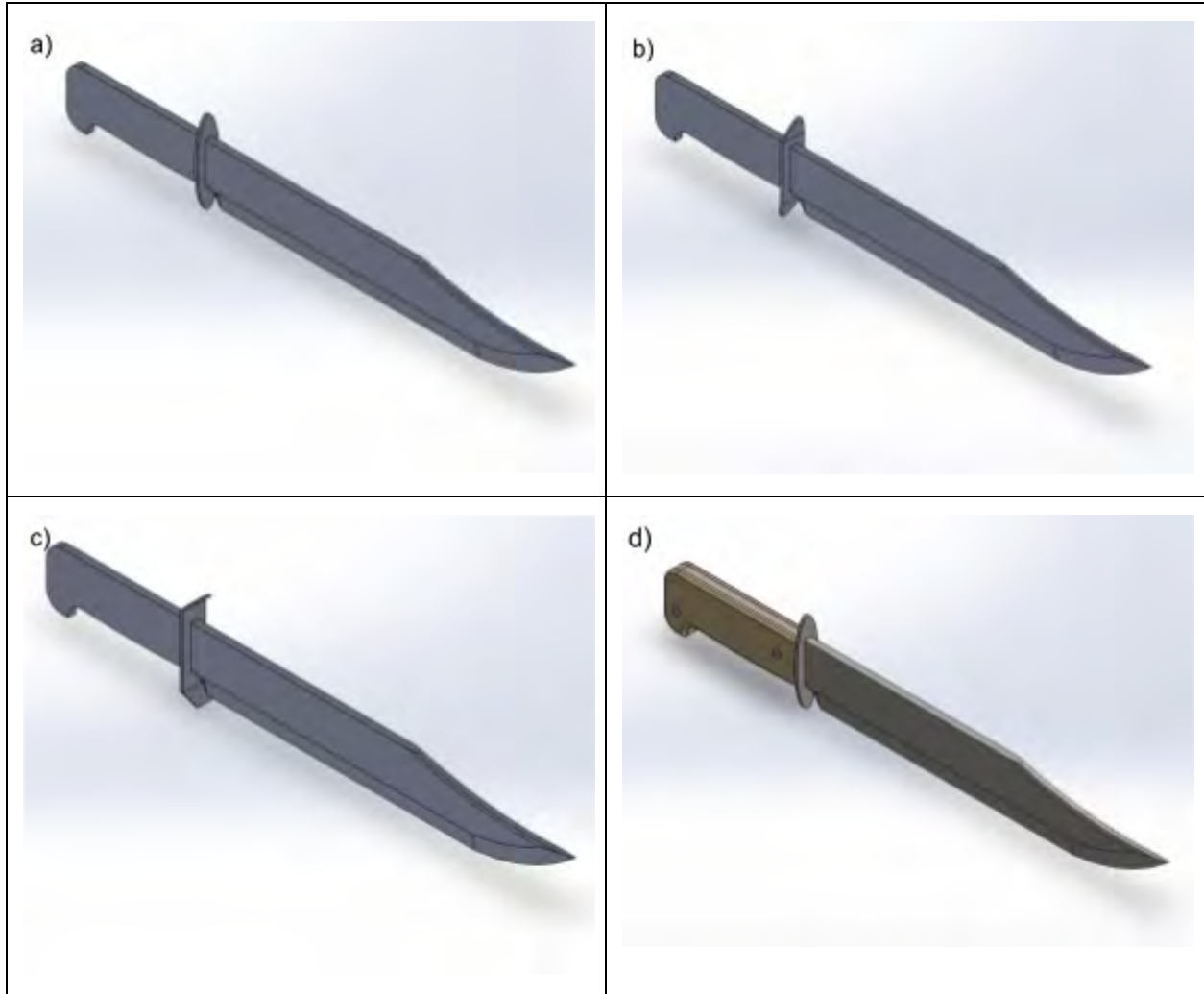


Figure 6. Isometric view of classic guard (a), s-guard (b), and u-guard (c) models (d) shows what a full assembly of the classic guard would look like

From the initial design, there were only two main changes that were made in the final design of the knife. The first change was an increase in the guard thickness to 0.3 in. The second change was to make the edges of the guard chamfered. These changes were made in order to reduce thermal stress found when modeling the cast, which will be talked about in the next section. An isometric view and a detailed drawing of the final design is shown in Figures 7 and 8, respectively.

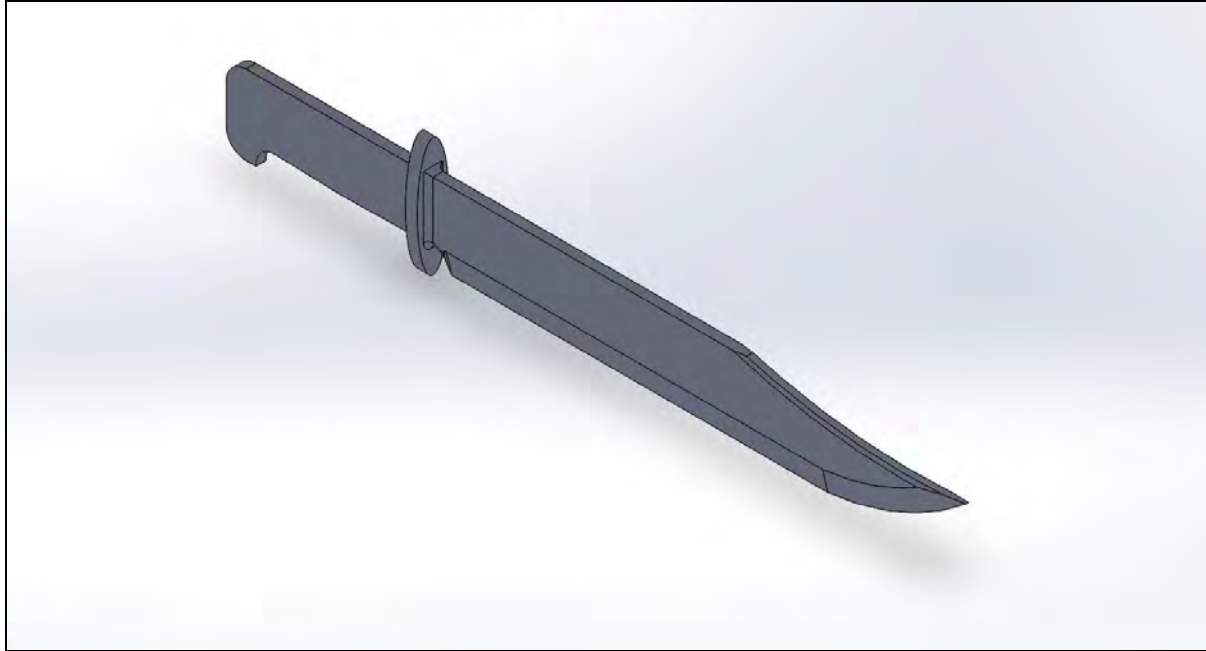


Figure 7. Isometric view of final design of the bowie knife

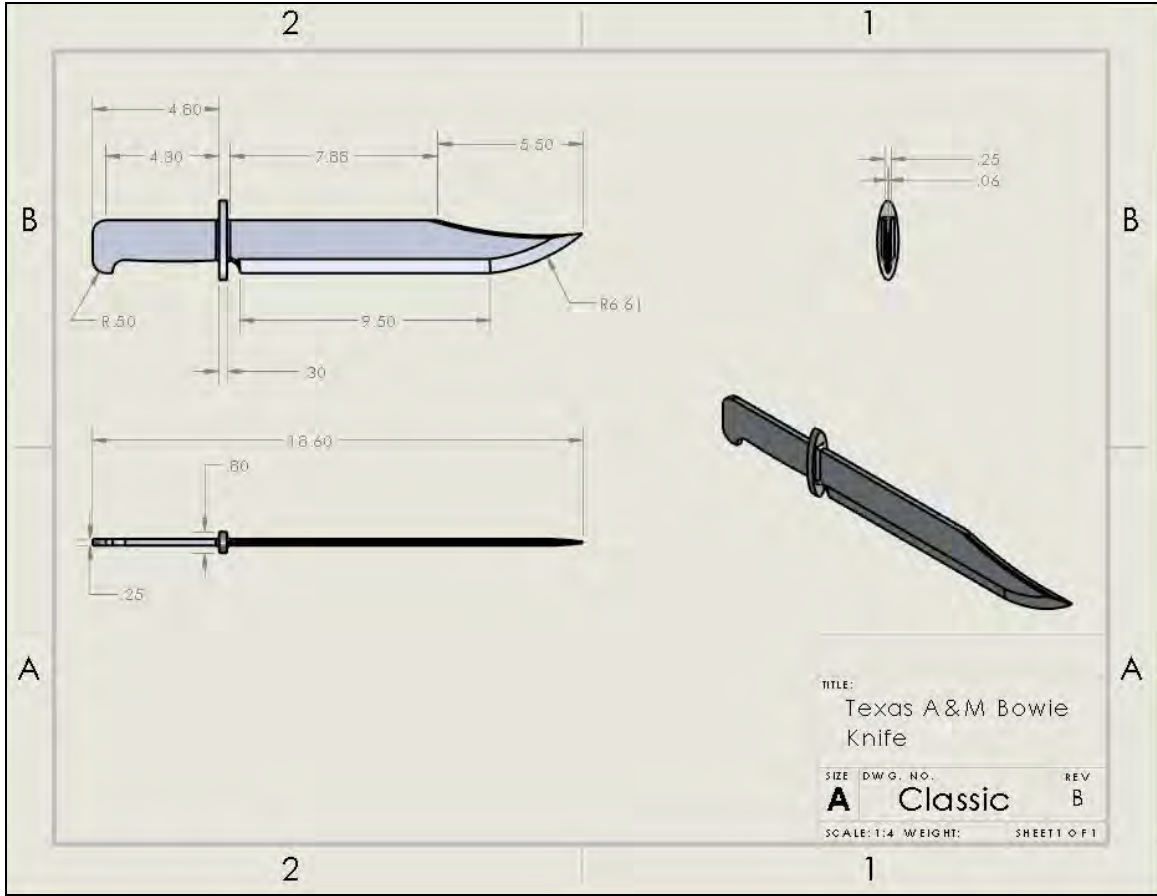


Figure 8. Detailed drawing of final design of the bowie knife

Casting Optimization and Design Approach

As a main challenge of this competition is to cast instead of forge a knife, it is important to discuss the differences between the casting and forging. Forging allows for a better control of the microstructure and increased hardness with deliberate introduction of dislocations and mechanical phase transformation. This is why most high quality knives have their blades made through forging. Without the convenience of forging, knives made through casting must be creatively cast and heat treated to achieve desirable properties.

At first, we were considering two different options for casting: investment casting and sand casting. Investment casting can be separated into four main steps. The first step is the creation of the pattern with a polymer or wax. The second step is to make a ceramic shell from the polymer pattern. The pattern is dipped into a ceramic slurry and is fired, creating the ceramic shell. Once the ceramic is hardened, the polymer is burned out of the mold. The third step is to pour molten metal into the ceramic shell. The final step is to break the ceramic shell off of the cast. The main positive of this method is the high fidelity of the cast, due to how the ceramic shell is made.

Sand casting can be separated into three main steps. The first step is the creation of the pattern with a polymer or wax, much like in investment casting. The second step is to pack the molding sand around the pattern in some type of container. The final step is to pour the molten metal into the mold, replacing the polymer pattern with metal.

After considering our options, we decided to use investment casting because of its better geometric fidelity and surface finish as compared to sand casting.

After deciding which casting method to use, our attention shifted to adding gates and channels for the molten steel to pour into the mold. With the help of Gary Hinds from Texcast, a model with the gates using our initial model was made. However, the area around the guard was experiencing a large amount of heat stress due to the guard being too thin and the hard edges between the blade and the guard. After increasing the guard thickness and chamfers to the guard, two more models with gates were made. One model had 1 ½” gates and the other had 2” gates, shown in Figure 9 (a) and 9 (b) respectively. Due to there being more heat stress with 1 ½” gates, we decided that it would be better to choose the model with 2” gates.

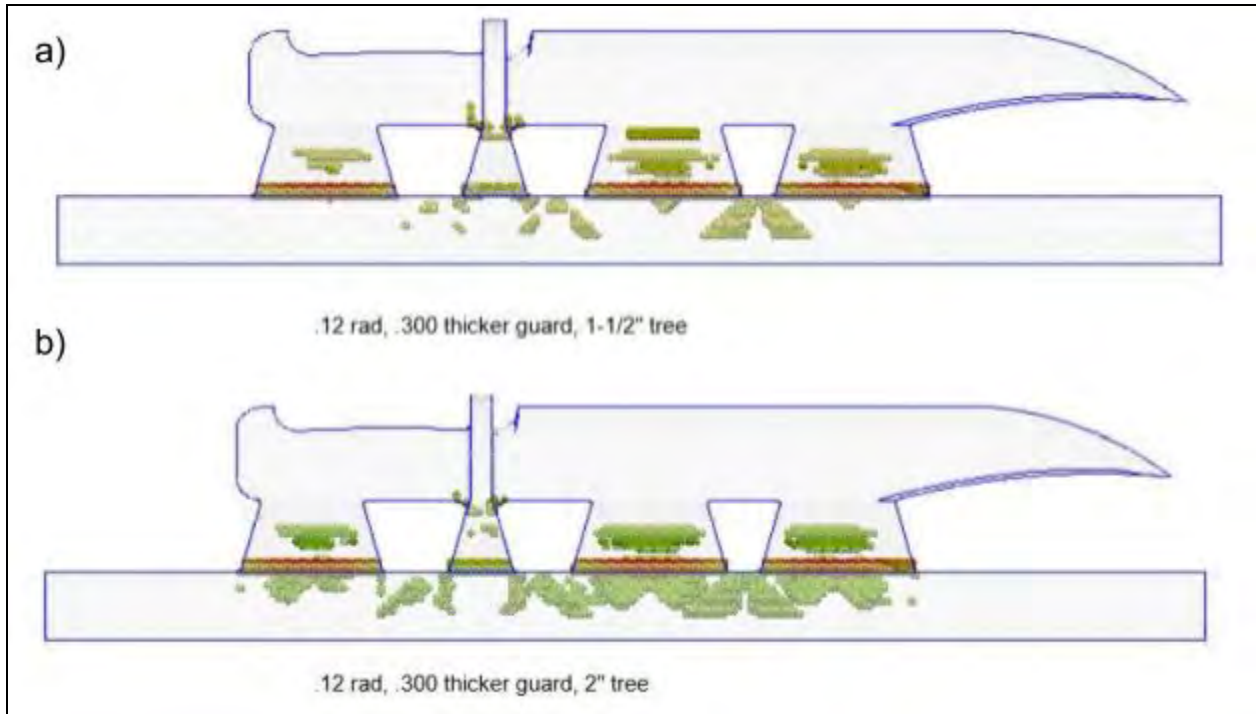


Figure 9. Diagrams showing calculated heat stresses in the bowie knife models with 1 ½'' gates (a) and 2'' gates(b)

With the model of the gates finished, we started to focus on how to make the mold for our casting. We started with how many knives would be printed. We decided to make 10 knives in response to Mr. Hinds informing us that a quarter of our casts would most likely fail. Once the number was decided, we moved on to how the initial polymer mold would be made. We decided to use 3D printing because of its ease of use and the high fidelity that could be achieved with this technique. However, due to the large size of our mold, we could not find a 3d printer big enough on campus to fulfill our needs. Luckily, 3D Systems was willing to assist us in making our polymer molds. These polymer molds are shown in Figure 10.

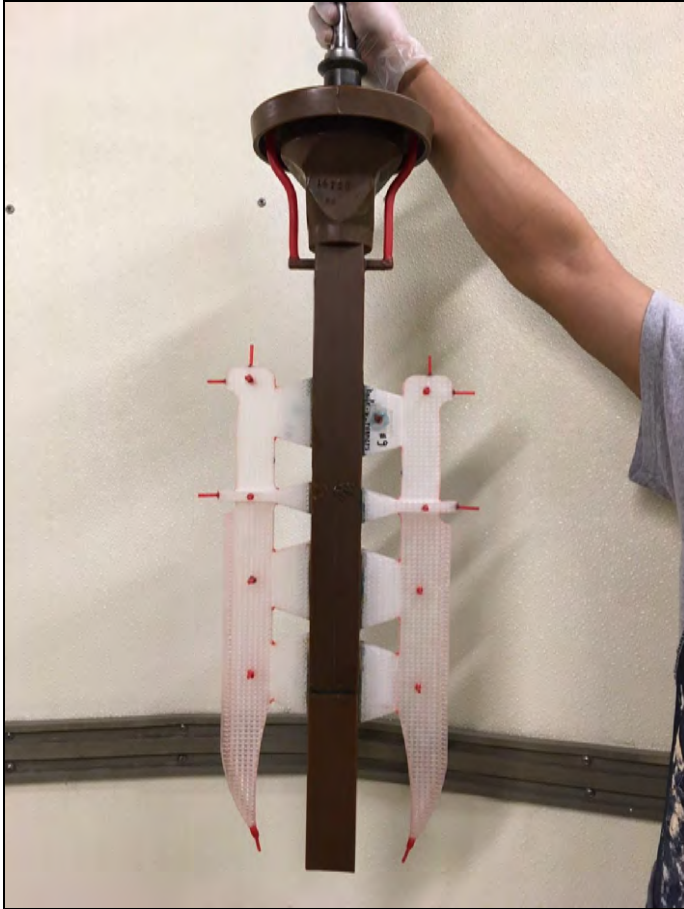


Figure 10. Polymer molds with gates attached to a metal runner

After the polymer molds were made, the molds were sent to Texcast where the molds were attached to a metal runner, creating the trees for our cast. Then, the ceramic shells were made from the trees. One of these shells can be seen in Figure 11 (a). The casting process was carried out, successfully casting five out of our planned ten knives. A problem that arose was the thermal gradient on the ceramic shell causing it to crack. To fix this, the shells were preheated to 500 °F. One of the full casts after being shook out can be seen in Figure 11 (b). In Figure 12, the rough knife with the risers removed and one with both the gates and the risers removed are shown.



Figure 11. Ceramic shell of our casting tree (left), Final cast of one of our casting trees after being shook out (right)

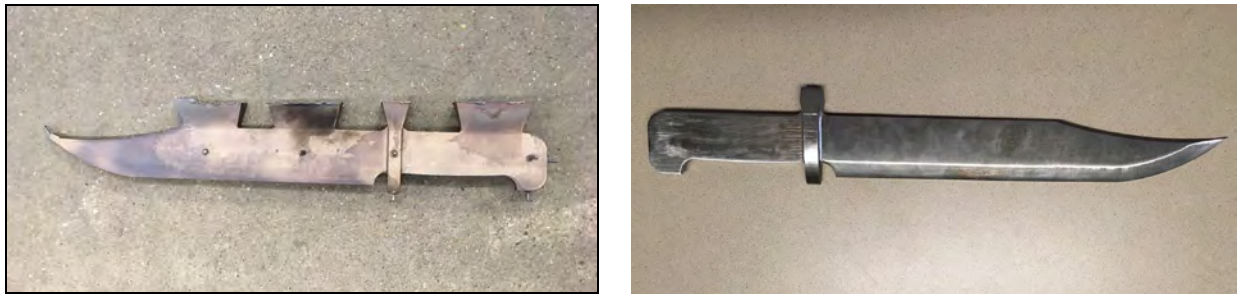


Figure 12. Rough knife with risers removed (left) and with both the risers and gates removed (right)

Material Selection

When picking our alloy composition for the blade, multiple things were taken into consideration: the wear resistance, edge retention, corrosion resistance, impact resistance, strength, formability, and the cost. Traditional iron workers used damascus steel to build lots of different weapons, such as daggers, swords and knives. Damascus steel is an iron matrix composite that created a relatively strong knife for its time. However, damascus steel has to be forged and is known for having poor edge qualities, which was a huge factor in our decision since we know that our knife is going to be put through an edge test.^[9]

We considered some carbon steels. Carbon steels are known for being very strong alloys that have good edge retention, hardness and formability. They are also used in various industries and applications due to their relatively low cost. One big problem that we found with possibly using carbon steel is that they have poor corrosion resistance. We know that the knife is going to be shipped to the testing location, so it must be able to resist corrosion until then. If the blade

heavily corrodes before it is tested, the mechanical properties will be altered and could possibly lead to premature deformation. Not to mention corrosion ruining the aesthetic of the knife. We thought about coating the blade in oil to prevent corrosion, but this seemed like a less reasonable idea than just picking a stainless steel. Stainless steels tend to have all the great properties that carbon steels have but their high chromium contents tend to lend them superior corrosion resistance.

Stainless steels were very interesting contenders for our alloy composition, but their impact resistance, wear resistance and hardness were simply not good enough for rugged tests. However, a further search into stainless steels yielded a wear and impact resistant class of steels that was perfect for our project. We found that tool steels, which is a type of steel that is used in drill bits, knives and dies, was our best contender. Tool steels are known for having great toughness, wear resistance, hardness, and corrosion resistance. When looking at the different types of tool steels we focused on Molybdenum high speed steels (M series steels) and high carbon, high chromium, cold worked steels (D series steels).^[10] Our original candidate was M2 steel because of its great distribution of carbides, resistance to decarburization, and diverse applicability, but we had to eliminate this option due to its high price.^[11] We ended up choosing D2 steel for our blade composition due to its comparable-to-M2-steel toughness, but being considerably more affordable.

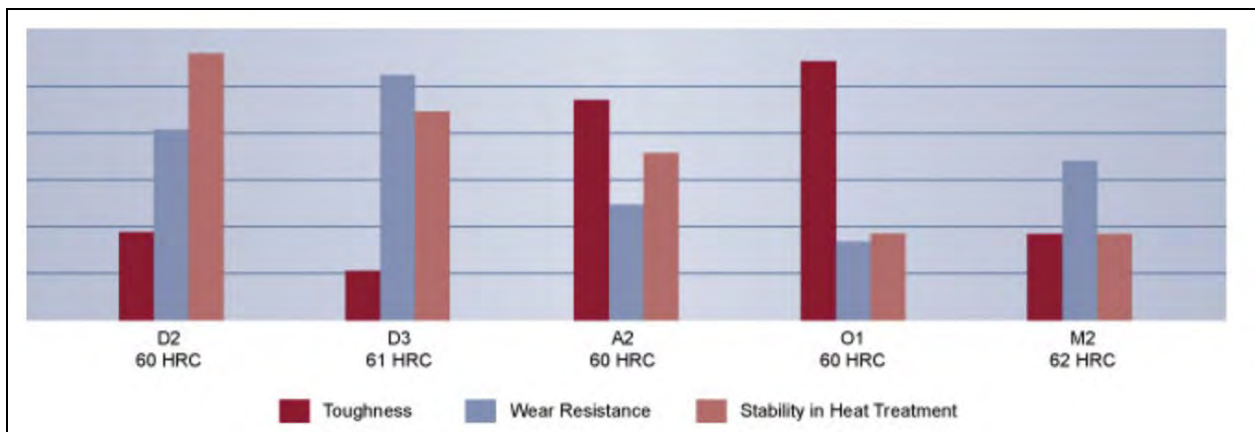


Figure 13. Comparison of different tool steels and their relative properties^[12]

D2 steels are made of carbon, silicon, chromium, nickel, molybdenum and vanadium. Its high carbon and chromium content allow for the steel to become very hard, around 55 to 62 HRC. This is crucial for its wear resistance and structural stability. Its high chromium content also gives it superior corrosion resistance in comparison to regular carbon steels. The nickel addition helps to improve the toughness, which is critical for impact testing. The addition of molybdenum also improves the hardenability and corrosion resistance as well, and the small addition of vanadium helps to promote a finer grain structure. A fine grain structure is desirable

in steels since it is an important factor in wear resistance and hardness. Overall, this composition should make for a good quality blade that will be able to hold an edge during a sharpness test and make clean cuts through most materials. Its high strength, toughness, and wear resistance should allow the blade to avoid any chipping, rolling or cracking during a strength test.^[13]

Element	Content (%)
C	1.40 – 1.60
Mn	0.60
Si	0.60
Co	1.00
Cr	11.00 – 13.00
Mo	0.70 – 1.20
V	1.10
P	0.03
Ni	0.30
Cu	0.25
S	0.03

Table 1. Chemical composition of D2 tool steel^[14]

Pecan wood is the state tree of Texas. As Jim Bowie died at the Alamo, it seemed fitting that this knife paid tribute to both Bowie and the state of Texas. We decided to use spalted pecan for the handle. Spalted pecan is pecan wood that has been aging outside for about a year or two. This causes mineral migration to the wood grains which results in a beautifully detailed grain pattern. This beauty-through-age mirrors the rich history of the Bowie Knife and its strong connection to the state of Texas.



Figure 14. Sample of spalted pecan wood used for the handle

When making the handle, we realized that we would need to reinforce the wood to prevent chipping or cracking in case the judges decide to hammer the butt during a strength test. We soaked the spalted pecan wood in polyurethane for five hours and then let it cure on a rack at room temperature. When arranging the orientation of the wood, we aligned the grain parallel to the spine. If the handle is cross-grained then the wood would easily split along the grain when force is applied on the butt or when the knife is being swung and striking a hard surface.^[15]



Figure 15. Our spalted pecan wood curing after being soaked in polyurethane

Heat Treating Process

Heat treatments are processes that change microstructure through deliberate heating and cooling cycles. Achieving the correct microstructure is how we attain the mechanical properties we want, such as: strength, toughness, ductility, and hardness. When a knife is forged, the metal is heated up, but still in its solid state, and is mechanically worked into the shape that is desired. This process leads to a finer grain size and better mechanical properties such as tensile strength, fatigue life, and strength. For casting, the metal is heated up to its liquid state and then poured into a mold of its desired shape. When the liquid metal cools in the mold, the grains are free to grow, which leads to a coarser grain size and worse mechanical properties. This is why choosing the correct heat treatment is critical for a cast part.

The traditional heat treatment process for D2 steel is to preheat the oven, austenize, quench, and then temper the steel. When doing research into D2 heat treatments, each step has a temperature and time range that will change the hardness of the steel. Finished D2 steel hardness typically ranges from 55 HRC to 62 HRC, but our desired hardness was around 58 HRC to 60 HRC. Our target hardness should result in a knife that keeps an edge but is not so brittle as to crack or shatter during testing.

To ensure that the furnace achieves the proper austenization temperature, we did a slow preheat of 222 °C /hr until we got to 650 °C , equalized the knife for ten minutes, heated to 788 °C, equalized it for ten more minutes, and then heated it slowly until we got to our desired temperature of 1010 °C. In literature we found that the austenization temperature for D2 steel can range from 788 °C to 1010 °C, but we chose to treat at 1010 °C because having a higher temperature allows the carbides to dissolve back into the matrix and produce a more resilient material. The knife was held at 1010 °C for 2 hours and then air-quenched in front of a fan. D2 steels are air hardening steels that can be quenched in air. So, after two hours of austenitizing the metal, we quenched the metal by placing it onto a table in front of a fan until it reached 70 °C . Immediately after reaching 70 °C, we tempered the knife.^[16] The tempering range we researched was between 200°C and 300 °C. We chose 232 °C for the tempering temperature because we wanted a tougher knife. Tempering at a lower temperature will result in a harder material, but we did not want to make it too brittle.^[17] After tempering the knife for two hours, we turned the furnace off and let the knife stay inside overnight to slowly cool. After all of the heat treatments were completed, we tested the hardness of our blade using a Vickers Microhardness Indenter (HV) and found that our blade had an average hardness of 690 HV which is about 58.1 HRC.



Figure 16. Removal of the knife from the heat treatment steel foil wrapping

Knife Fabrication

Due to the COVID-19 pandemic, we were cut off from appropriate tools and workspaces. However, we were able to jury rig a polishing setup with a drill press and a 5" adhesive sanding disk bit. D2 steel, and all tool steels for that matter are incredibly wear resistant. We persevered, and while this required a great deal of hand working, we were able to grind and polish the knife in this way. We started with 40 grit disks, then worked our way through 80, 120, 220, and finally 320 grit disks. This, along with the use of TurtleWax Polishing Compound allowed us to achieve a near mirror finish on the blade.

There was an issue with drilling the pin holes in the tang. The knife came to us at about 48 HRC, but as mentioned, D2 steel is incredibly abrasion resistant. After destroying two drill bits attempting to get through the blade, we ended up driving 3 hours to Genesis Precision

Machining in Dallas to use their CNC machine. Even with proper equipment, we still broke a 7-fluted carbide endmill by the time we had drilled holes in all of the knife blanks.



Figure 17. Blade with roughened tang

The tools we had available for the handle were only a hacksaw, a dremel tool, and sandpaper. The pecan wood used for the handle is spalted pecan. This wood gets its beautiful grain pattern from approximately 2 years of laying on the ground aging. Because the wood is technically rotten, it had to be reinforced by soaking it in polyurethane. Before reinforcing the scales with polyurethane, we first cut and ripped the scales from a 5' board of pecan with the hacksaw. The untreated wood was so weak that when we finished one of the cuts, the saw slipped and smacked the board and took a nickel sized chunk off the corner of the board. Once the scales were completed, we roughened the tang and back side of the scales to give the epoxy a good surface to grab on both sides. We used J-B Weld epoxy and a $\frac{3}{8}$ " steel rod for pins and clamped the entire system together. Once the epoxy cured, we removed the extra wood around the tang and shaped the wood to form a handle for the knife. As the wood is already infused with polyurethane, no finish was used for the handle. The final cutting edge of the knife was put on by hand with a sharpening stone.



Figure 18. Epoxying the spalted pecan wood to the handle



Figure 19. Side profile of the exposed tang during the shaping of the handle



Figure 20. Overall view of the handle before epoxying the pins in place

Knife Ornamentation

We decided to emblazon the historic phrase “Remember the Alamo” on one side of the knife, and a line drawing of the Alamo on the other as a dedication to Jim Bowie and all those who fought bravely at the Alamo. The date on the knife is actually the date of the Battle of San Jacinto, the battle that won the Texas revolution. It was at this battle that the phrase “Remember the Alamo!” gained its renown as a popular battle cry amongst the Texas Revolutionaries. It commemorates all those who fought bravely at the Alamo; all of whom died to create a sovereign Texas. The design was put on the blade by first coating it with metal laser marking spray, and then using a CO2 laser to “write” the design onto the blade. This process gave us the flat back images on both sides of the knife.



Figure 21. Overall view of the back side of the handle with decorations



Figure 22. Overall view of the front side of the handle with decorations

Video Production

The video was produced using iMovie based on clips and images of the knife in multiple stages of its development and some historical stock photos of both Jim Bowie and the Alamo. Covid-19 forced us to all record our audio in our home using the software Audacity rather than the in house recording studios at Texas A&M. It was important for us to have all five team members heard so we made sure to include audio recorded by each individual as a way to represent our joint effort in creating this knife.

Conclusions

Over the past few months, the Cast In Steel project tested our group's ability to think critically, our ability to adapt and overcome, and helped cement an appreciation for the bowie knife and steel design. If we were given a chance to start changing certain aspects of the entire journey. It would be getting a lot of the research done much earlier. This is because it would allow us to work on the casting, and more importantly, the finishing process much earlier. If the current global situation didn't occur, we would have gotten to use the proper equipment for polishing and add the finishing touches to the knife. However, because of the pandemic, we had to adapt our process and made compromises to push this project forward as a team. Some individuals had to take more responsibilities that became time-consuming because the proper equipment wasn't available to use. However, regardless of the adversity that came our way, we adapted by finding ingenious methods to resolve the lack of available equipment.

Special Thanks

On behalf of our team from the MSEN department from Texas A&M, we would like to sincerely thank you for your support and generosity during these past couple of months for the Cast In Steel Competition 2020. Even with all of the setbacks from COVID-19, we were able to build a beautiful bowie knife that we are all very proud of. We value your ongoing support and sponsorship and look forward to possibly working with you in the future for other possible projects. Our department is also aware of all of the effort and assistance that you have given our student project, and they would like to thank you too.

Special thanks to all of our sponsors :



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