Submission for the 2020 Cast in Steel Competition by the University of Northern Iowa

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Commercial Foundry: Omaha Steel

Abstract

For the 2020 Cast in Steel competition this year the Steel Founders Society of America has selected a bowie knife for the competition piece. From frontiersmen to the United States Military, many have used this popular style of knife because of utility, durability, and heritage.

Supported by Omaha Steel, the student team from the University of Northern Iowa designed and manufactured a knife for competition. The knife is made of 440C stainless steel and was manufactured with the use of 3d sand printing. The knife features a sweeping blade and a paracord handle. This shape was chosen for its style and is ideal for chopping. The paracord handle was selected for its utility and ease of manufacture.

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History

The Bowie knife, The most famous American knife there is. Named after the famous James Bowie who fought and died at the Alamo. James Bowie was famous for his knife skills and for carrying a large knife. James Bowie ended up in multiple knife fights and attacks throughout his life that he became famous[1].

This large knife he carried however, is most likely not the same knife design that is the famous bowie knife. Soldiers around the U.S talked about how much they wanted a knife like James Bowie but didn't really know what it looked like besides being an extremely large knife. Rezin Bowie, James Bowie's older brother, knew a knife smith named Pedro who helped solidify characteristics of the bowie knife such as heavy cross guard, coffin shape handle, and sweeping clip blade.

Design

During the design process many designs were drawn up that ranged from classic and traditional bowie knives, to futuristic modern looks to finally the design we selected with is for a majority a traditional design but a exaggerated curve upon the blade to allow its function to withstand more blunt force use. The original sketch is shown in figure 1 below.

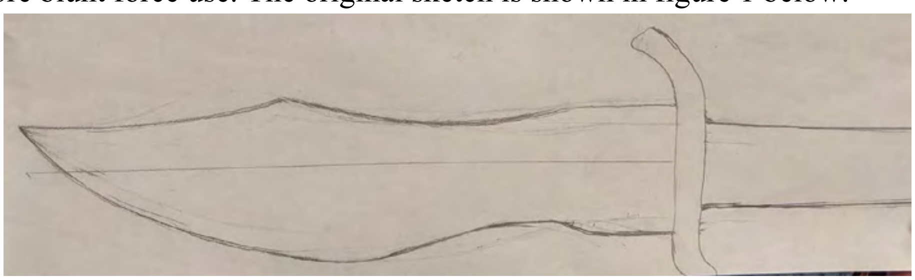

Figure 1. Rough draft first design of bowie knife

At 0.400" this design has a larger than normal blade thickness to give the blade more area to disperse shock during blunt hits, and also allows for direct casting in steel into a near finish shape. Because of this, little post process of the blade other than heat treatment, grinding, and sharpening.

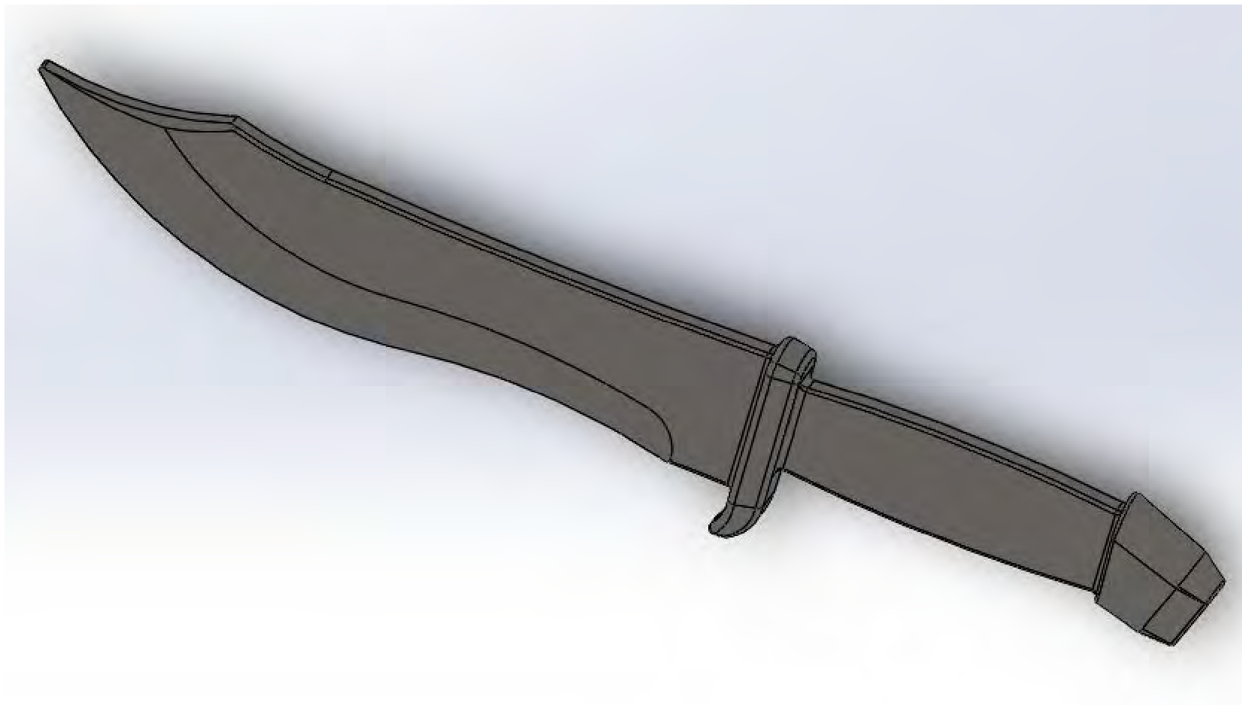

Figure 2. The knife was designed in SolidWorks.

To turn this idea into a viable casting it was created in the CAD program SolidWorks. The 3D model, like the one in figure 2, not only helps with our gating design, but can also be easily imported into MAGMASoft. Casting simulation software, like MAGMASoft, calculates the filling and solidification of a casting and shows a large variety of scientific and technical data. This tool facilitates in the optimization of casting design. It also shows the areas of high probability that casting defects will occur.

A standard AFS gating design of 1:2:2 was used during the rigging process to allow smooth flow and even distribution of steel within the blade. As seen in figure 2, the full gating had 4 blades per one mold allowing for one riser to feed 2 blade pummels above the crossguard of each blade a blind riser was also pleased to pull shrink out and bring the center of gravity of the blade as close to the crossguard as possible and balance the blade at the contact point between the blade and crossguard. An overflow was designed into the knife edge to allow an edge that was as thin as possible without either shrink pulling the edge or metal not penetrating the thin section due to surface tension.

The knife edge was also well vented to cool the thin section quickly and again allow the edge to be as thin as possible with the constraints steel causes. Venting also is used to help encourage metal flow by reducing gas buildup in the mold.

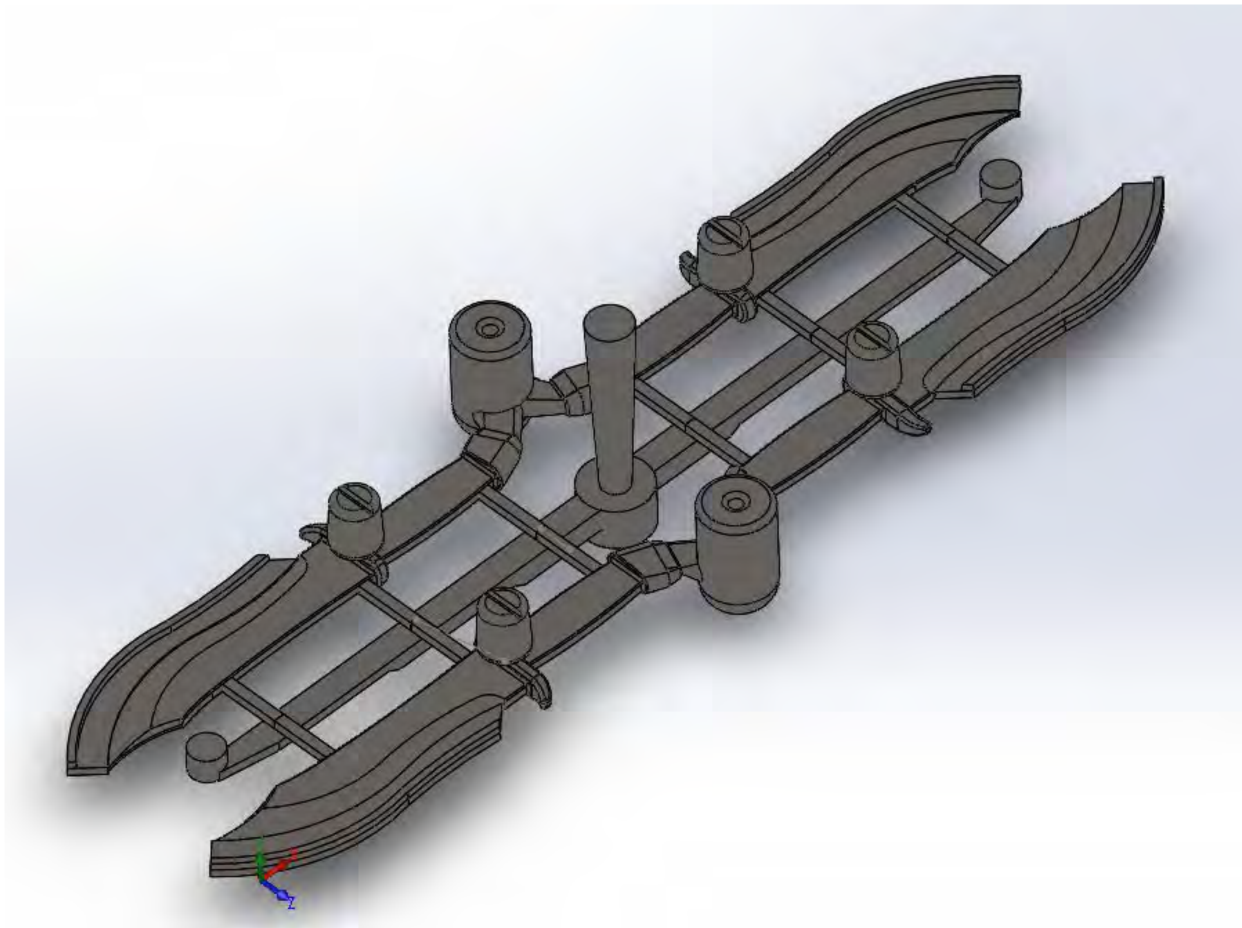

Figure 3. The image above shows the final knife design with rigging

Molding

Using the designed gating, a Cope and Drag were designed and converted to STL format to allow easy printing of molding using the 3D printing process allowing excellent use of our hard gating design with quick ease. The Additive Manufacturing Center at the University of Northern Iowa donated two printed molds for this project. The advantages of 3d printing molds are that it is more suitable for complicated shapes and the relative quick turnaround time because the need for hard tooling is eliminated. A picture of the printed mold is pictured below in figure 3.

For the bowie knife molds, an ExOne S-MAX printer was used. This printer uses a furfuryl alcohol-based binder system to build the mold. One part of the binder system is mixed into all of the sand. The sand is then laid down one layer at a time. Finally a printhead goes across the sand applying the second part of the binder only to the areas that should be solid[2]. One of the main drawbacks to this method is the stepping that occurs due to the layering process. An image of the molds is shown in figure 4.

Figure 4. Above is a picture of the 3d printed mold

After the molds were printed they had to be cleaned and prepped for shipping. This is done by using brushes, a vacuum, and compressed air to remove the loose sand from the mold. Once the loose sand was removed, the molds were packaged and sent to Omaha Steel for prep and pouring.

The Omaha Steel team made some alterations to the to better prepare the mold for pouring. First an alcohol based coating was applied to the mold. The coating helps with surface defects such as burn on and metal penetration. It can also improve the surface finish.

In addition to the coating, Omaha Steel also altered the mold for better castability. As depicted in figure 5, the vents were drilled out to a larger diameter and a large pouring cup was added. These modifications were done to help the metal flow by increasing the permeability and adding head pressure. The larger pour cup also made for an easier target for the workers pouring the metal. These modifications can be seen in figure 5 shown below.

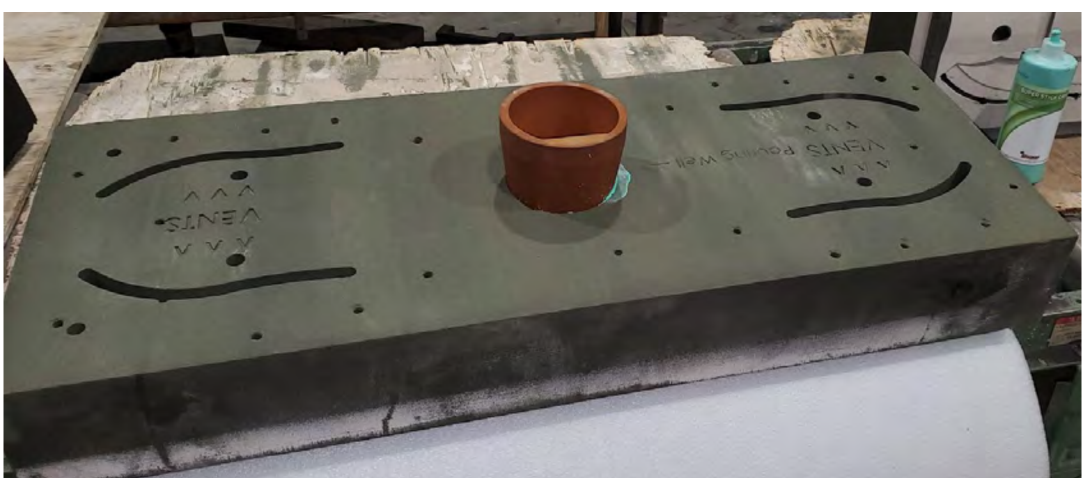

Figure 5. Modifications to the mold such as larger pour cup and vents can be seen above.

Metal Selection and Pouring

The alloy chosen to be used for the bowie knives was 440C. This alloy is a common alloy in knives due to its exceptional wear and corrosion resistance. Though hard to machine, 440C is a martensitic stainless steel alloy known for its high hardenability[3]. Target and actual chemical composition is shown in the figure below.

CHEMICALS

	---------- Standard Range ----------		
Element	**From %**	**To %**	**Actual %**
Al (Aluminum)			+0.014
C (Carbon)	.95000	1.20000	1.17000
Cr (Chromium)	16.00000	18.00000	17.60000
Cu (Copper)	.00000	.00000	
Mn (Manganese)	.00000	1.00000	0.71700
Mo (Molybdenum)	.00000	.75000	0.02500
Ni (Nickel)	.00000	.00000	+0.10200
P (Phosphorus)	.00000	.04000	0.00900
S (Sulfur)	.00000	.03000	0.01800
Si (Silicon)	.00000	1.00000	0.70700

Figure 6. This table shows the range and actual chemical makeup of the 440C alloy used.

The two molds were poured on location at the Omaha Steel Foundry in Wahoo, Nebraska. The steel was melted in an electric arc furnace and underwent shrouding to help ensure the quality of metal. Below is a picture of an Omaha Steel employee pouring the molds.

Figure 7. A bowie knife mold being poured at Omaha Steel is shown.

Rough Cleaning and Heat Treat

After solidification and the casting has been broken out of the mold the casting and rigging receives an initial heat treat to soften the metal to allow post process to occur. The initial heat treat as well as the rough cleaning were all performed at and by employees of Omaha Steel. After the initial heat treat, the first step is degating. A plasma cutter was used to cut the rigging off, the resulting knives can be seen in figure 8. Following the plasma cutter, the riser, partings, and flow off areas were ground to within 1/16”-1/8” of the final shape.

Figure 8. Raw castings after degating are shown.

The castings had a small, but not insignificant shrink defect in the crossguard of the knife. This defect had to be welded to fill in the gap. Before welding could occur, the shirk was excavated using carbide burrs. Welding was performed with a 410 electrode after the knife was preheated to 600F. Finally the weld was ground and dressed to blend into the knife. Pictures of the shrink and repair can be seen in figure 9.

Figure 9. The shrink defect is shown before and after welding. (but before the weld was dressed)

Finish Grinding and Final Heat Treat

When the knives arrived at UNI what was left was a post weld heat treat, grind, heat treat, tempering, and final grind. The post weld heat treat was the same as a process anneal. The recipe was provided by Omaha Steel and is as follows: “Anneal in furnace at 1400F for 4 hours, cool slowly in furnace to 1100F, then ok to pull load for cooling in still air.” The hardness was not checked before the process anneal, however after the anneal the hardness measured 10 Rockwell Hardness C.

After the anneal, grinding began. Because the knife’s size had to be increased to help with castability, there was a decent amount of material to be removed. Many tools were used in the process including: pedestal grinders, 50 and 60 grit 26” grinding wheels, a 3” 50 grit belt grinder, and an angle grinder with wheels 40-80 grit. The knife proved to be tough to grind and had pockets of martensite. Though the surface of the knife was difficult to grind, the edge was still able to be sharpened. An image of the knife after grinding can be seen in figure 10.

Figure 10. After grinding, the knife is near final shape.

Once the blade was close to the final shape, it was heat treated for a final time. The final heat treat included a quench and a temper. Following the guide Heat Treater's Guide[3] , the knife was equalized at 1400F before increasing the temperature to 1850F. Once at temp, the knife soaked for 45 minutes then was oil quenched.

Following the oil quench the knife was tempered. The furnace was set at 330F and the knife rested inside for two hours. The target for this heat treat and tempering was to reach 58-60 Rockwell Hardness C, however only a Rockwell Hardness of 48 was attained. Due to time constraints, a second attempt was not made.

After the heat treat the blade was subjected to its final processing. Using many of the same grinding tools mentioned above, the final shape was formed. To sharpen the blade, a 8" dual grit 100/320 sharpening stone was used. The final step was to make and mount the handle. The handle was simply made by whipping 5/32" 550 nylon paracord around the knife. The paracord handle provides grip and can be easily untied should the need arise. Pictures of each side of the final knife can be seen on the title page to this report.

Conclusion and Reflection

A bowie knife was manufactured by students from the University of Northern Iowa and submitted to the Cast in Steel competition held by the Steel Founders Society of America. The bowie knife featured 440C stainless steel construction, a sweeping blade design, and a paracord handle.

The molds were printed at the Additive Manufacturing Center at UNI and poured at Omaha Steel. The blades were then cleaned and sent to UNI for final grind and heat treat.

References

1. Nickens, T. (2004, February 01). The History of the Bowie Knife. Retrieved June 26, 2020, from https://www.fieldandstream.com/history-bowie-knife/
2. Trinowski, D. (2019, January 01). Understanding 3D Sand Printers and Binder Technologies. Retrieved June 26, 2020, from https://www.foundrymag.com/molds-cores/article/21931923/understanding-3d-sand-printers-and-binder-technologies
3. Chandler, H. (1995). *Heat treater's guide*. Ohio: ASM.

Acknowledgements

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