

# Steel Founders Society of America Cast In Steel Competition

Michigan Technological University

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### Background:

Kicking off the axe casting competition is literature research. No one on the team had experience with designing axes so building a fundamental understanding of their design through history was critical. The goal of this research is to understand the design decisions in Viking axes, how the design has changed through the years and then finally create our own design cherry picking design features to improve upon the Viking design while maintaining a strong Viking influence.

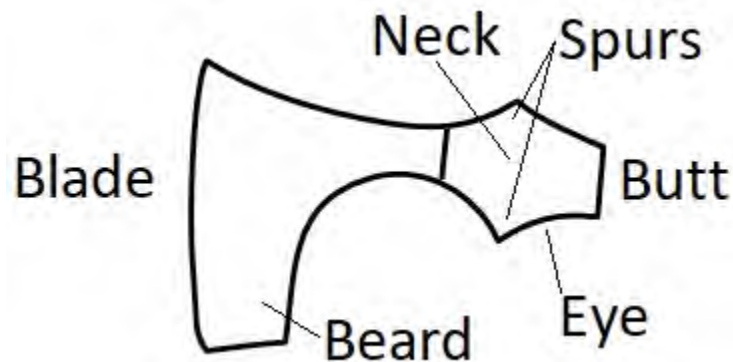


Figure 1: Anatomy of an axe

Many styles of axes exist, a majority of research was done into the various Wheeler styles. Wheeler style axes generally come with a blade that has a beard that extends well beneath the bottom spur, but also extends upward to the top spur and in some cases past it. As design developed with time the general trend is a thinning of the neck and increasing the curvature of the blade to extend well past both spurs and the butt of the axe became straighter. We did not want to be solely locked into mimicking the latest Wheeler design, so it was also important to notice some of the designs that drastically changed how the axe looked. This included Wheeler B and K designs. The Wheeler B features a very small neck similar to the above figure. This design makes the beard seem a lot longer than what it actually is. The Wheeler K design takes an exact opposite approach. Utilizing a thicker neck and drastically decreasing the length of the beard in favor of a blade that extends upward past the top spurs.

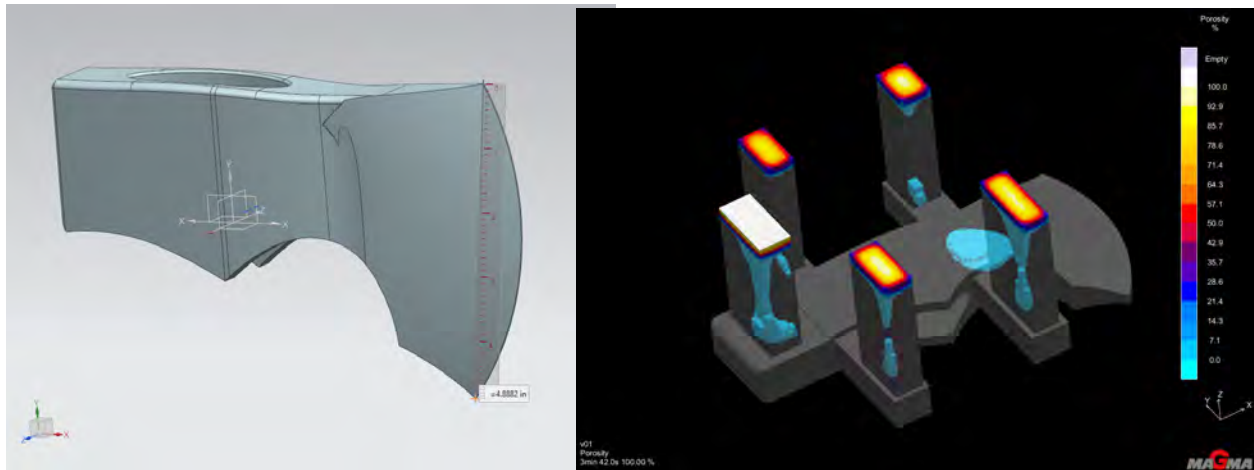
The Wheeler design was the clear focus of research, the group was more or less familiar with how axes look from many cinematic appearances along with understanding how common axes found in hardware stores look. These influences certainly have contributions to all designs made and these ended up being an amalgamation of Wheeler and Petersen styles.

### Design:

It is said that when groups are tasked with creating objects they are not familiar with, groups that design iteratively often outperform groups tasked with creating a single perfect object. This is the design methodology that we followed to design our axe. We produced 3 designs based on what literature review suggested a Viking axe should look like[1]. We

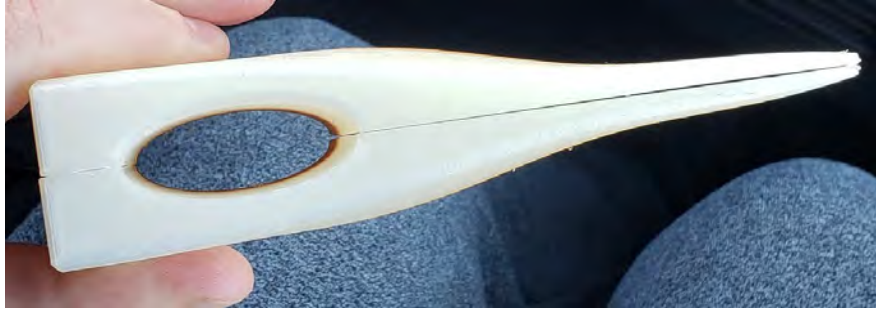
sketched and modeled our designs, then ran Magma simulations to assess castability and critiqued each other's work.

Our first design was a blend of a modern single-bit Michigan pattern axe blended with a Peterson type B[1]. This design was thought to have the look of a Viking axe with the performance of a single bit-Michigan pattern axe. The eye of the axe is tapered to allow the axe to be handled traditionally and the weight is 5lbs. The butt of the axe is such that it will give good balance to the large amount of material that makes up the bit.



Design 2 was influenced not only by Viking axes, but hatchets as well. Originally designed to be 10" in total length the model was scaled down to 6.5" to better accommodate the volume of the 3D printer (Ultimaker 3 Extended) used to print it. Stylistically the beard was added to capture the Viking aesthetic whereas the overall size places in a class of hatchets. Compound curves were designed into the blade as seen from the top view. These curves were meant to keep a hefty amount of thickness in the spine of the blade, adding forward weight but ensuring strength and reducing risk of fracturing. The center of balance falls short of an ideal location, but the forward momentum would help in chopping scenarios at the expense of faster fatigue in the user. The size of the blade and the center of balance were clear deciding factors when we chose to not select this axe for the competition submission.





Design 3 is by far the most massive. It is a large two-handed axe that deserves a long handle and a strong wielder. This design was based on the appealing shape of the Peterson type B[1]. It deviates from the pattern somewhat with a much larger radius leading from the eye to a narrower beard in order to aid in the distribution of forces from the blade. It also has a diamond wedge bit to conserve mass while strengthening and supporting the edge and reducing the overall force needed to drive it deep into a log or chop down a tree. The availability of axe handling materials dictated the shape of the eye, which is a slim oval instead of the more round ones found in traditional axe heads.



### **Material Selection:**

Manganese is an important alloy in steel for several reasons and is present in virtually all steels in amounts of 0.30% or more. Manganese is a carbide former and has a marked effect on slowing the gamma-to-alpha transformation; therefore, it increases hardenability. Further, manganese in steel is important because of its ability to counter hot shortness, that is, the tendency to tear when being hot formed. In steel, iron and sulfur combine to form a sulfide that has a relatively low melting point. When the steel freezes, this sulfide solidifies in the grain boundaries. On subsequent reheating for rolling or forging, it tears or breaks apart. If

manganese is added, it combines preferentially with the sulfur and forms a manganese sulfide of higher melting point, which by its distribution and nature eliminates hot shortness.

Chromium affects the properties of steel in a number of ways. It has a marked effect in slowing the rate of transformation of austenite; that is, it greatly increases the hardenability of any steel. Additionally, relatively large percentages of chromium increase oxidation and corrosion resistance. However, because the amount of chromium used in alloy steels is 2.0% or less, its principal function for AISI-SAE alloy steels is to increase hardenability. While alloying elements are sometimes used alone, they frequently are used in combinations of two or more elements because it has been found that the use of smaller amounts of two or more elements is more effective than large amounts of a single element. For instance, chromium is generally used with nickel, molybdenum, or some other element[2].

Both Manganese and Chromium were used as alloying elements in our final cast material. The purposes of using these alloys was to increase hardenability, corrosion resistance and help us control how we maneuver through the various steel phases during heating and cooling. Other alloying elements are present in the final cast material to compliment the Manganese and Chromium which were Nickel and Silicon. Altogether this composition favored an axe that would match the industry standard in hardness while keeping strength to ward off fracturing, an ideal combo when designing a Viking axe.

### **Casting:**

Michigan Tech has a strong foundry program, with faculty experienced in many areas of casting. Faculty experience is mainly focused in cast irons, brasses, and bronzes, but seldom with steel until this academic year. In the interest of laying the groundwork to expand and update our capabilities with a relatively simple project like this, we decided to produce our axe in-house. Our foundry partner Badger Alloys in Wisconsin contributed a generous amount of knowledge to the project. With their guidance on gating, venting, mold preparation, and thin-section flow among other things, we designed our patterns to better accommodate steel casting process.

The Gerdau Steel Castability (GISP) Advanced Metalworks Enterprise (AME) team is the first project in many years to do steel casting in our foundry. Their project is focus on the molten properties of steel and graciously gifted the axe casting team with their material after testing was complete. We took the opportunity to run an initial test pour with their steel to validate the most technically vulnerable pattern and casting process, design 3, out of an aluminum killed 1080 plain carbon steel at 1500°C. With the pattern as designed and using large pouring basins, the test went flawlessly.

The competition axe was cast from 5160. The charge material was built from GISP's unused 5117 and an appropriate amount of de-sulfurized carbon was added to bring the composition up to 0.6 wt% carbon. Using the successful pattern, but with smaller pouring basins, we cast two of design 3 along with three of design 2 and one of design 1. All molds and cores were made with uncoated chembond sand made



the day prior to casting.

Three heats were required to fill the molds. The first two were charged with the raw 5117 and carbon additions while the third used portions of excess "pigged out" steel as well as from the pouring basins and risers of the first heat. The charge material was melted in the same inductotherm furnace heated to 1600°C. The heat was slagged and aluminum killed with an arbitrary amount of aluminum introduced to the melt from an extruded rod. Upon pouring we noticed that we couldn't pour nearly as fast as with the test pour which we identified as something that could be problematic. On the second heat we attempted to pour faster, but the small basins were being filled to capacity. As a result of the slower filling, we encountered what appeared to be cold shuts or flow defects fairly deep in the surface.

Our chemistries were not in the range of 5160, but this being the first time a steel was cast in our foundry in a while, I'd say we got pretty close.

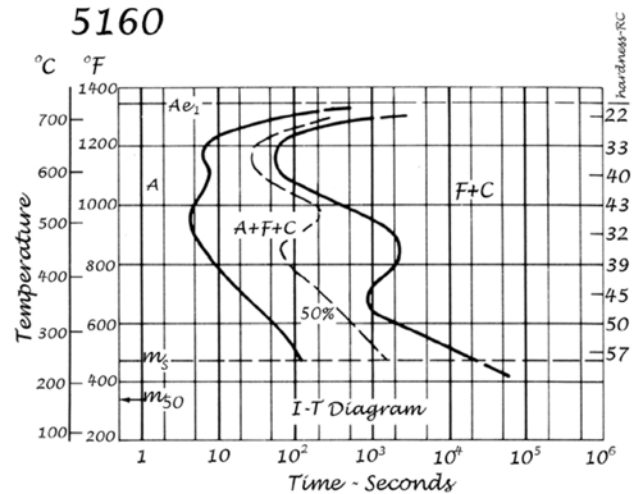
	The Axe	AISI 5160 [3]
C	0.532	0.56 - 0.64
Si	0.07	0.15 - 0.30
Mn	0.649	0.75 - 1.0
Cr	1.195	0.70 - 0.90
Ni	0.244	-
Al	0.052	-
P	0.016	-
S	0.022	<=0.040



## Finishing:

### Heat treatment:

Our heat treatment plan was originally going to mostly follow the commonly cited ASM guide, but based on a very recent post by Dr. Larrin Thomas on his blog Knife Steel Nerds as it highlights possible flaws in the ASM method if precise temperature control is not maintained as well as where hardness and toughness can be maximized. From this, our heat treat is as follows:



1. 1500°C hold for 30 minutes in cast iron chips and graphite
  - a. To austenitize and reduce decarburization.
2. Oil quench
  - a. The oil was old and unknown, Parks 50 would probably be better. This resulted in a brinell hardness of around 573, which correlates to low 50's Rockwell C.
3. Cryo treatment in a -80°C freezer for 1 hour
  - a. Warmer, but for longer in order to transform retained austenite to martensite.
4. 400C temper for 1.5 hours with a 30 minute cool down at 1 hour
  - a. This is designed to reduce temper embrittlement and maintain some hardness.

In the as-cast state, our steel had a brinell hardness of 273, 285 10mm ball, 3000kgf, 10s which correlates to about 30 Rockwell C. According to the heat treat, our quenching target was 58.5-59.5 HRC (in a forged 5160). We reached a hardness of approximately 573 HBN which equates to a Rockwell C in the low 50s. Our off chemistry, and specifically the low carbon, might be to blame for this, but might prove beneficial as axes tend to have lower harnesses than knives.

For handles, the modern material of choice is hickory. We wanted to cut the handle and shape it ourselves out of a board, but despite the help of our contacts, we could not locally source any before the deadline. We considered using something like oak or ash, but that wasn't really appealing to us. We eventually settled on a 39" hickory handle blank from a local hardware store and set to working it. The process of handling involves many cycles of test fitting and filing to get the handle to seat snugly, at which point wooden and metal wedges, a concession to modern axe making, were driven in to seat the handle firmly in the eye. Sanding, shaping, and cutting the handle to size took place, also meticulous and careful tasks, took place. When the assembly was finished to our satisfaction, a light char finish was applied to the handle near the eye and several coats of boiled linseed oil were applied. We noted at several points in the process, as during the literature search and finishing stages that while the blade requirements are generous, the handle maximum length seems anemic.





**Acknowledgements:**

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The GISP AME team for letting us piggy back on their last pour and for the use of their leftover steel.

## Citations:

- [1] "Axes - The Viking Age Compendium." [Online]. Available: <http://www.vikingage.org/wiki/wiki/Axes>. [Accessed: 09-Apr-2019].
- [2] J. L. Dossett and H. E. Boyer, *Practical heat treating*, 2nd ed. Materials Park, Ohio: ASM International, 2006.
- [3] "AISI 5160 Steel, annealed, 25 mm (1 in.) round." [Online]. Available: <http://www.matweb.com/search/DataSheet.aspx?MatGUID=8c9219c15c1e4ba9bf32871d4494776d&ckck=1>. [Accessed: 09-Apr-2019].