SFSA Cast in Steel Technical Report

University of South Alabama Axe Team

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Our design, in accordance with the principle that an axe should be a multi-purpose tool, but with the goal of still being viable as a weapon, was modeled after a historical Viking axe design with a head shape most suited for general use. The steady angle of the head leads to exceptional capabilities for splitting wood, and the mass and size of the scaled design lends itself to use for felling trees for lumber. Both these traits lead to a design that would provide a sufficient amount of momentum to cleave any armor despite not being as agile or maneuverable as a more conventional battle axe.

Figure 1: Petersen Type-I Top reference courtesy of National Museums of Scotland

The image in Fig. 1 was used as a reference for the top side dimensions. The axe came from the Kiloran Bay Viking Burial. According to the National Museums of Scotland, "The iron axehead was found in a Viking grave mound at Kildonan on Eigg in the Inner Hebrides. The man was buried with weapons and ornaments from Scandinavia and the British Isles between 900 and 950." [1].

Figure 2: Petersen Type-I historical reference

The figure above is a different shot of the same axehead from Fig. 2. It was used as a historical reference for the design [2].

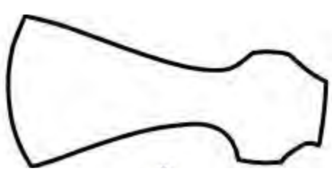

Figure 3: Petersen Type-I artistic reference

The drawing in Fig. 3 side profile is an artistic rendition of the Petersen Type-I axe. It was chosen to be a reference for the design due to the incomplete spurs on the artifact [3]

Our team created a head of the "Peterson type I" classification. The head shape was scaled up in order to fit the competition parameters. While the historical axe head design was used with a smaller handle and held in one hand, we increased the handle length to the maximum allowable for the competition in order to fit the scaled head. This final design was chosen from several initially created by the University of South Alabama team members, and was selected due to its excellent resilience and low stress concentrations as determined by finite element analysis (FEA) simulations performed upon the models. The final design and one of the designs considered are found below in the model demonstrating stress concentrations.

For the figures below, SolidWorks 2017-18 was utilized to produce the FEA results. The following assumptions were made:

- 400 Newtons (N) Radial Force within the Hole of the Axe Head
- 900 Newtons (N) Force transmitted through the edge
- Hole has Fixed Geometry

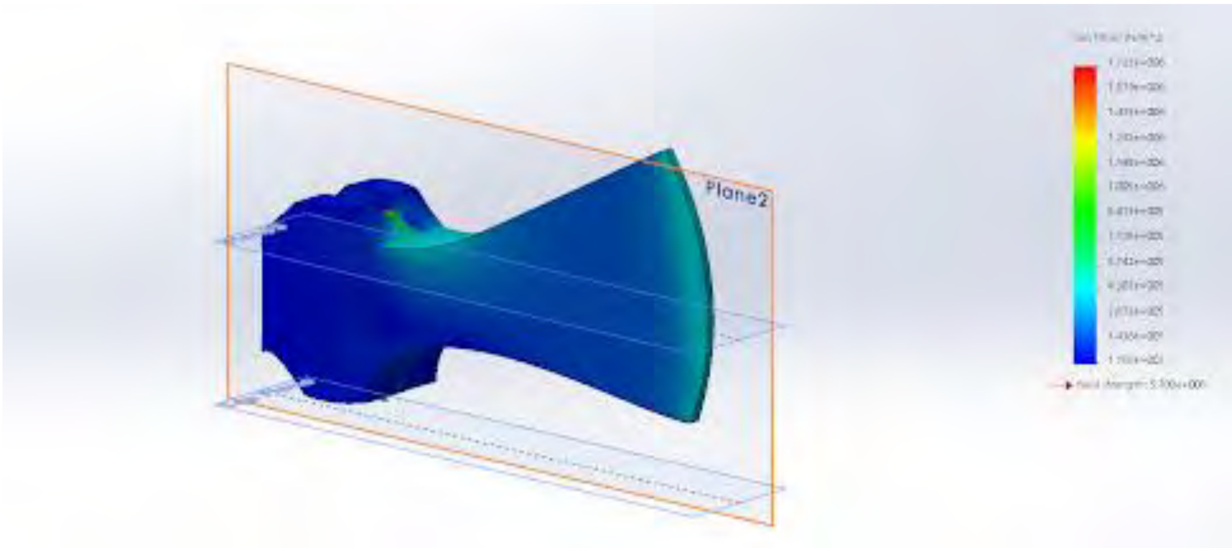

Figure 4: Peterson Type I (FEA)

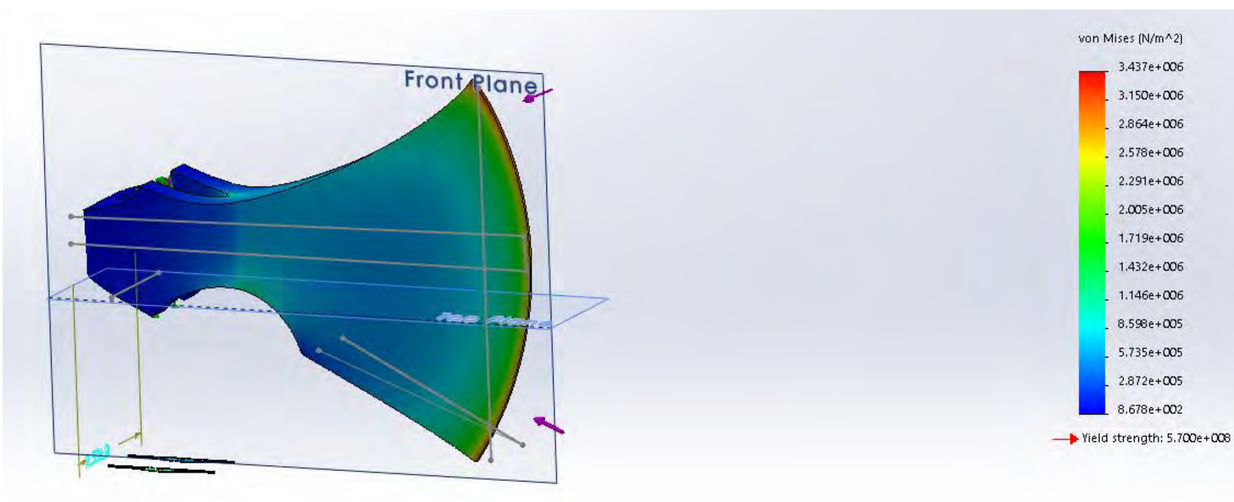

Figure 5: Peterson Type E (FEA)

ACI-ASTM CA-15 steel was the material utilized in the production of the axe head, with 12.55% Chromium by weight. CA-15 is known to have the highest ductility among the cast martensitic stainless steels [4]. Martensites describe the crystalline structure of the particular metal through heat treatment of stainless steel. Typically, martensitic metals are used in the event where strength and wear resistance is prioritized. The applicable mechanical properties were quoted from the makeitform.com listed in the references. The casting then underwent heat treatment in accordance with ASTM A743 and A217 standards with the steel first being normalized at 1750 ℃, tempered at 1100 ℃, and finally annealed at 1450 ℃. Each of these processes occurred over a period of one hour per inch of material thickness and were followed by air cooling.

The properties utilized for the stress analysis are as follows:

Table 1: Mechanical properties of CA-15

Brinell Hardness	220	
Elastic Modulus (E)	190 GPa	28 Mpsi
Fatigue Strength	370 Mpa	54 kpsi
Poisson's Ratio	0.28	
Shear Modulus	76 GPa	11 Mpsi
Tensile Strength (Ultimate)	700 Mpa	100 kpsi
Tensile Strength (Yield)	570 Mpa	82 kpsi

Fig. 1 and 2 displays the Von Mises Stress on both designs under the assumed conditions. For the Peterson Type I listed in Fig. 1, the maximum stress was determined to be approximately 1.722 Mpa located within the hole. For Peterson Type E listed in Fig. 2, the maximum stress was determined to be approximately 3.427 Mpa located on the edge of the blade. For its versatile application, Peterson Type I was chosen for this competition.

Table 2: ASTM CA-15 Alloy Composition

Element	**Composition (%)**
Iron (Fe)	85.57
Chromium (Cr)	12.55
Silicon (Si)	0.80
Manganese (Mn)	0.56
Molybdenum (Mo)	0.14
Carbon (C)	0.12
Nickel (Ni)	0.11
Copper (Cu)	0.10
Phosphorus (P)	0.02
Aluminum (Al)	0.01

Figure 6:3D printed mold for casting. With holes for risers visible.

Our axe head was cast using a 3D printed sand mold through Howell Foundry. Images of the mold design for the three axe heads cast for testing and final assembly are found below, and demonstrate the head design as well as the risers and gates used to feed the casting during solidification and pouring. After casting, the axe heads were shaken out of the mold, and the pieces remaining from the risers and gates were removed. Finally, the pieces were sandblasted.

Several advantages and disadvantages come with 3D printing of molds for casting. Notably, only a CAD model is needed for the casting process, thereby eliminating the need for a pattern maker in the production. There is no need for specialized tooling, even for extremely complex designs. Moreover, the pattern/mold production rate is significantly increased due to the 3D printing process.

On the other hand, the iron oxide, typically added to sand molds to avoid cracking, is much more difficult (and expensive) to include in a 3D printed mold. Furthermore, if the mold is not heat treated before shipping, the hardeners may not prevent the mold from warping during transit. 3D printed molds often produce tessellations which appear on the casting. They are typically not detrimental in any manner, but it will affect the quality of the piece's surface finish without significant buffing/removal. Of note, these tessellations can be seen on our final design as we felt it contributed to its rough, rustic appearance, and acts as an indication of the unusual process by which it was produced.

Figure 7: Assembled mold, ready for pouring.

After their production at Howell Foundry, the axe head was transported to the University of South Alabama, where the assembly, final processing, and rudimentary testing occurred. The rough edges produced during the casting process were ground down to slightly smooth the edges. The hickory handle, of standard design for an axe handle, was affixed using a wooden wedge. To further ensure the head was secure, JB Weld™ brand steel reinforced epoxy was used to fill any gaps between the wood and the metal [5]. Finally, a grinder was used to sharpen the blade, and the axe was tested by attempting to split large, dried tree stumps. During this testing, we found that the axe was capable of cutting deeply into and splitting wood. After testing, some slight deformation of the edge was noted. Unfortunately, with the facilities available, additional hardening was not possible, so the design was finalized by cutting the handle to 30 inches. Additional sharpening was completed using hand files to bring the blade to a finer edge.

Figure 8: Closeup photo of axe head

Figure 9: Full profile photo of axe

Acknowledgements

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