Steel Founders’ Society of America Michael Beining

2019 Cast in Steel Competition- Technical Report Kyle Brown

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Introduction

The Steel Founders’ Society of America Cast in Steel competition provides a unique opportunity for university students to collaborate with a steel foundry to design and produce a useable, cast replica of a 10th century Viking axe. Two undergraduate students from the University of Wisconsin-Milwaukee (UWM), Ahmad Elsharef and Kyle Brown, collaborated with Badger Alloys, Inc. of Milwaukee, WI, to design, pour, and process the axe head. The industry advisor for the project was Michael Beining, a plant metallurgist and current PhD student at UWM.

Alloy selection

Although Scandanavian axes produced around the 9th and 10th century were typically made of iron, the team wanted to make the axe out of a strong, hard, corrosion resistant material, capable of maintaining a sharp edge and withstanding forces from the chopping impacts. CA-40, also known as Grade 420 martensitic stainless steel, was the selected alloy for axe head. The high carbon content, when compared to the other 400 series steels, gives this alloy high strength, and allows it to form martensitic structures upon heat treating. It is high in hardness, and maintains these properties at temperatures up to 650 °C. This material is often selected for use in surgical equipment, for its durability, strength, and ability to maintain a sharp edge.

Mold Design

The students expressed interest in utilizing the Kuka 6-axis mold milling robot at Badger Alloys to fabricate the sand mold. They then used Solidcast simulation software to design the axe head, along with the proper sprue, gating, and riser dimensions, to produce a sound casting. Once the designs were completed, the files were sent to Badger and uploaded onto the milling robot software by one of the company’s engineers. The robot then carved out the pattern in accordance with the uploaded file onto two large sand blocks, which ultimately became the cope and the drag of the mold. There were two axe head patterns carved into the sand mold, to allow selection of the better casting to be processed. The two halves of the mold were then coated in a water-based refractory wash, and then finally glued and clamped shut. Figure 1 shows the drag side of the mold, as well as mold closed and ready to be poured.

Figure 1: The drag side of the mold on the left, and the closed and completed mold on the right.

Melting and Casting

Once the mold was completed, it was scheduled to be poured on a 1,000-pound heat of CA-40, melted in an induction furnace. Each axe head had a pour weight of 45 pounds, and there were two test bar keel blocks poured along with them. Once the molten bath was taken up to the proper temperature, a preliminary sample was analyzed in the lab, and additions were then added to the bath to bring the chemistry into specification. The team selected a pouring temperature of 2900°F to ensure proper filling of the thin section of the casting. The two axe heads were then cast, along with the two test bar keel blocks. Figure 2 shows the axe head and keel block molds immediately after pouring with hot top on them.

Figure 2: The axe heads and keel blocks immediately after pouring, with the addition of hot top.

The castings were then shaken out and cooled in still air. They were taken to be shot blasted with carbon steel shot, and then to the abrasive cut-off saw for gating and riser removal. Figure 3 shows the castings after shot blasting before and after removal of the gating. The castings had a good surface finish, filled completely, and were ready for heat treatment. There was a minor welding repair that was done on the drag side of one of the castings due to a small sand inclusion.

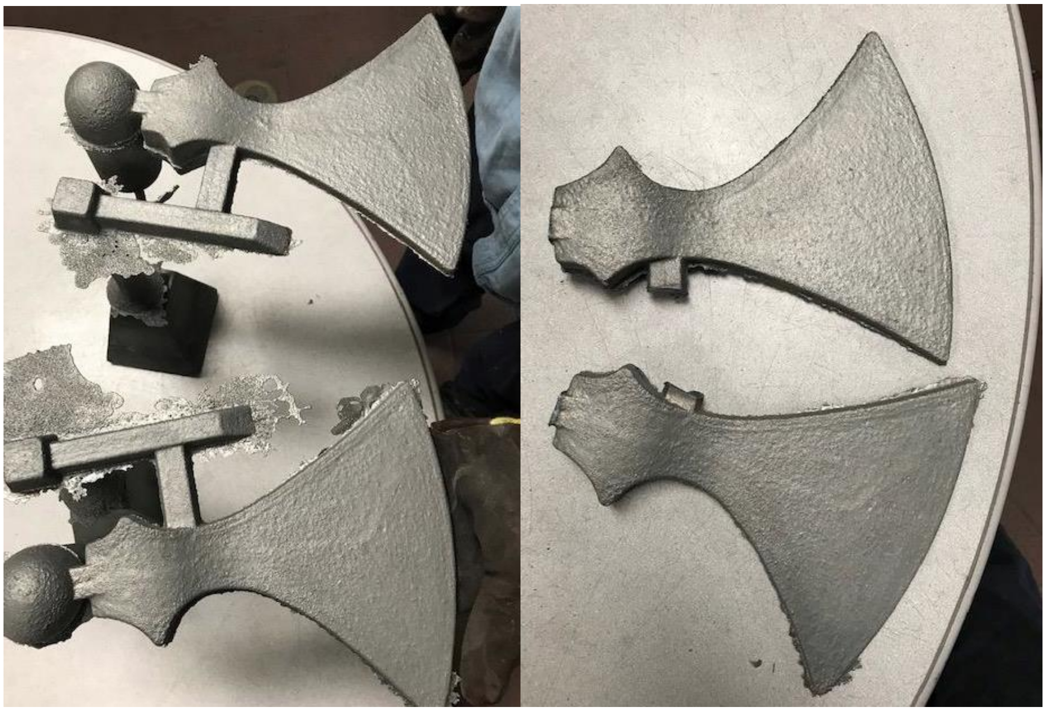

Figure 3: The casting before and after cut-off removal of the gating and risers, after they were blasted in steel shot.

Heat Treatment

Four test bars were cut off from the two test bar keel blocks poured. A Brinell hardness measurement was taken on one of the as-cast test bars, showing a hardness of 558 BHN. This meant that the castings were very hard and brittle, so annealing was required first to stress relieve the castings. The castings and test bars were annealed at 1600°F for two hours in the lab at Badger, then taken out and still air cooled. They were then hardened at 1850°F for two hours and air cooled, followed by tempering 1200°F for four hours, and air cooled. Harndess measurements on the test bar showed 290 BHN, so the castings were not heat treated again, and the test bar was sent out to a third-party lab to be analyzed. Table 1 shows the ASTM A743 mechanical property requirements of CA-40, as well as the results of the tempered test bar sent out for analysis.

	Tensile (ksi)	Yield (ksi)	% Elongation
ASTM A743 Requirements	100	70	15
Test Bar Results	148	76	11

Table 1: The ASTM A743 requirements and the results of the tempered test bar.

Although the test bar failed elongation requirements per ASTM A743, the team decided to forgo tempering a second time, because they thought having a harder material would be more suitable for an axe head, at the expense of some elongation.

Final Processing

The better of the two axe heads were then selected for further processing and taken to UWM. There, the Society of Automotive Engineers offered to mill the handle hole in their machine shop, per the design given to them by the team. After the handle hole was machined, the casting was ready for a rough grind, and then sharpening. At this point, the team purchased a 3-inch by 3-inch by 36-inch piece of ash wood from a lumber supply shop to fabricate the axe handle. This material was chosen because it is workable, very hard, and finishes nicely, and would be a suitable handle choice for an axe.

The axe head was ground using an angle grinder with an 80-grit pad on it. This was sufficient for buffing out any remaining small pinhole inclusions exposed after the steel shot blasting and provided a uniform surface finish before the final shot blast. The handle was then fabricated by first using a handheld wood planer to obtain the shape, and then sanded with various strips of sand paper. The handle was then shortened to 29 inches using a hand saw. Once the sanding was finished, and the handle was in its final form, it was finished with two coats of linseed oil. The inserting end was worked further, and a small slit was cut approximately ¾ of an inch into the handle to create the inserting end of the shim. The shim was fashioned by using the wood planar on another piece of ash wood. Figure 4 shows the axe head after its final stainless steel shot blast, as well as the handle after it was finished with linseed oil.

Figure 4: The handle after finishing with linseed oil, and the axe head after the final stainless steel shot blast.

Finishing

The axe head was taken back to UWM to sharped and attach the handle. Two wet honing stones, of 1000 and 3000 grit, were used to sharpen the axe. Both sides of the cutting edge were first repeatedly run along the 1000 grit honing stone. Care was taken to make sure that there was symmetry on both sides. It was then sharpened by running the cutting edge along the 3000 grit honing stone on both sides. Once the sharpening was deemed sufficient and finished, the handle was attached by inserting the end with the slot cut out into the handle hole on the axe head. The shim was then inserted into the slot first with a rubber mallet, and then hammered in. The remaining material was carefully removed using the angle grinder with an 80-grit grinding pad, and then finished by hand with some sand paper. At this point, the sharpened axe was completed and shipped to SFSA. Figure 5 shows the two faces of the axe after insertion of the handle, and Figure 6 shows the sharpened axe in its final form.

Figure 5: The axe head after the handle was fixed onto it.

Figure 6: The axe in its final form.

Conclusion

This axe challenge was an exciting and unique experience that had its own inherent obstacles, challenges, and frustrations that came along with it. The project took into accounts all aspects of foundry operations, including engineering, mold design, mold production, melting, casting, welding, and machining. This required organization, management, team-work, and open communication with supervisors in all areas of the foundry. It was a great opportunity to be exposed to and work in areas of production that your job may not normally require you to.

The biggest challenge came from the post-casting working of the axe head, when the team needed to select the proper way to grind, polish, hone, and sharped the axe head. This was the first axe challenge the three students have completed, and many of the decisions made were judgment calls, including the decision to not further temper the axe head, and the best method of polishing and sharpening it. This required seeking advice from experienced foundry personnel, including engineers, pattern makers, supervisors, and college professors, as well as online research.

The team was overall satisfied with the final axe product which gives a historic representation of an authentic Viking axe. We are grateful that SFSA puts on this challenge every year, and are eager to hear back about the results of the competition, as well as the feedback from the judges.