SFSA Cast in Steel 2026 – Horseman's Axe Technical Report

Youngstown State University Team – The Penguinators

YOUNGSTOWN STATE UNIVERSITY

Team members:

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Advisor:

Dr. Brian Vuksanovich

Foundry Partners:

Coronado Steel

Excellence Training Center

Executive Summary

The Youngstown State University (YSU) team set out to design and manufacture a cast horseman's axe meeting the requirements and demands of a 15th century battlefield. SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. The Youngstown State team worked with modern technologies and industry to create a cast horseman's axe fit for mounted cavalry combat.

The axe is a modern interpretation of the classic horseman's axe featuring similar design aspects to meet the demands of the time. These features include a curved blade and a long spike that was designed to pierce plate armor worn by knights. In this sense, the horseman's axe is a weapon used to destroy enemy armored troops when armor is too effective against the slashing or bludgeoning weapons of the time.

The team selected two materials for our axe. The axe head was cast out of Mar300 steel which is a martensitic aging steel with exceptional strength and toughness without sacrificing hardness. The handle was cast out of aluminum alloy A356 because of its low density, strength and ductility. Together, these two materials complement each other well for this project as they have similar heat treatment procedures. This allows us to cast the aluminum handle on to the steel axe head and heat treat them together as a single piece. An interstitial bronze layer was applied to the axe heads before the handle was cast to create a strong diffusion bond between the two metals. This leaves us with an axe head permanently attached to its handle without any glue or fasteners that could become undone during competition.

SolidWorks was used to design both the axe head and handle as well as their respective molds. MagmaSoft casting simulation software was used to help design the molds to eliminate porosity in the final castings.

Introduction

SFSA has created this competition to encourage students to learn about making steel products using the casting process and applying the latest technology available. The Horseman's Axe competition creates a unique challenge of adapting casting to produce a traditionally forged object. The Youngstown State team recognizes the challenge and applied modern technologies and some innovative techniques to produce our axe. Our goal is to innovate on previous years' success by further developing our overcasting technique with a dual material fully cast axe.

Team members

The Youngstown State Team, The Penguinators, consists of mechanical engineering students Joseph and Victoria, mechanical engineering technology student Kevin, and forensic science student Kelley. Our Team Advisor Dr. Brian Vuksanovich guided the team in casting techniques and design for manufacturing principles. The team's name, The Penguinators, is inspired by our objective to make a modern axe designed with engineering principles and the university mascot, the Youngstown State Penguins.

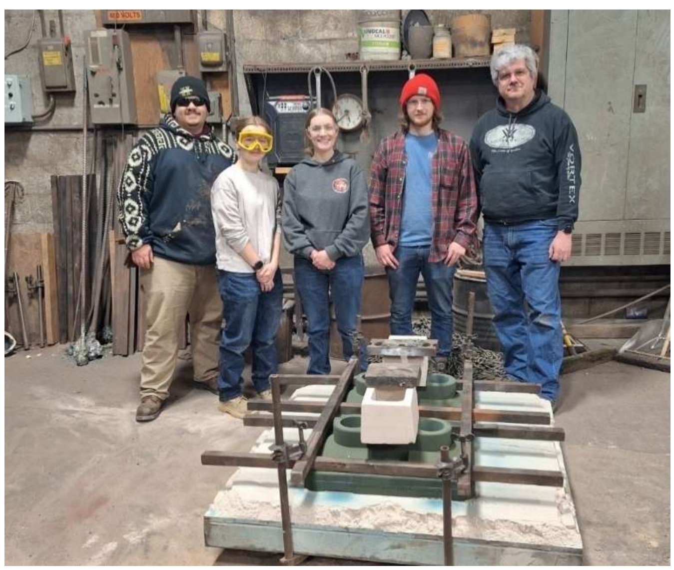


Figure 1: 2026 YSU Penguinator Team (From left to right) Kevin Otero, Kelly Karavias, Victoria Mathews, Joseph Bartlett, Dr. Brian Vuksanovich (Team Advisor)

Aesthetic and Functionality Choices

This year a horseman's axe was selected to be produced for the Cast in steel competition. Typically, these axes were forged by blacksmiths. In the spirit of the competition, the entire axe was cast except for the grip used on the handle. This allowed us to create a strong bond between the axe head and the handle without any glues or fasteners.

The axe head design was based on that of authentic 15th century Horsman's axes in the side profile featuring a curved blade and long spike. Due to the team's decision to perform an overcasting for the handle, the blade's thickness was significantly decreased for the handle to be cast around it. This saved weight in the axe head allowing the handle to be longer. In total, the axe head weighed1.3 lbs. of the allotted 3.3 for the entire axe.

The inspiration for the final design of the axe handle evolved from the design of modern framing hammers, mainly the Martinez Hammer, that features a titanium handle with an I-beam section and an ergonomic two-sided grip seen in Figure 2. The Martinez hammer acted as an example of a two-sided tool with an ergonomic grip attached to a strong, lightweight I-beam section. Modifications were made on the original design to better fit the use case, manufacturing method, and size of the axe. The assembly of the axe involved overcasting the handle onto the axe head without the use of fasteners. Laser etching was used to place the YSU logo onto the finished axe.

Figure 2: Martinez framing hammer used as inspiration for handle design.

Alloy Selection

When research for alloy began, several considerations were made regarding what material properties would be desirable for a horseman's axe. The axe head must have a high yield strength to deal with the high stresses experienced, impact resistant to not shatter while striking a target, and hard enough to pierce metal plates without deformation. The handle must have good ductility, toughness, and strength to resist the bending forces experienced during testing.

While several strong steels were looked at, the team narrowed the alloys down to three main steel alloys. A2, S7, and Mar300 which all scored high in all three categories. While the team did have success with A2 and S7 in the past, Mar300 won out due to having the best balance of these three properties and it had the interesting aspect of having a low heat treatment temperature. This allowed the team to look at alternatives to the wooden handle most axes have. Several Magnesium alloys were initially looked at, however due to mismatches in the heat treatment process with Mar300, aluminum alloy A356 was chosen due to its familiarity, availability, and near identical heat treatment to Mar300.

The team would be able to overcast the A356 handle on to the Mar300 axe head and heat treat the two materials at the same time. A silica bronze layer was deposited onto the axe heads before casting to act as an interstitial layer between the two dissimilar metals to ensure a strong bond. This is a further development of the technique used in Cast in Steel 2025 where the team cast a bonze hilt onto the George Washington Sword. The overcast handle is now a stress critical and heat-treated part of the design.

Casting Design and Process planning

The gating for the axe heads and handle was designed using SolidWorks and Magma Soft.

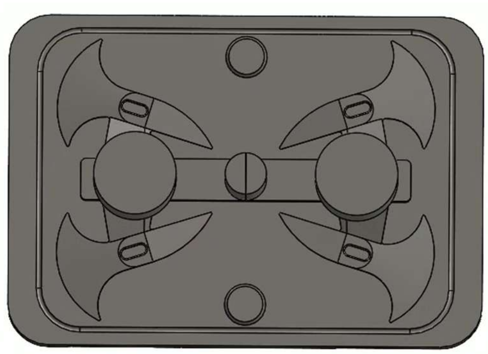
This can be seen below in 

Figure 3. The axe head mold was designed as a two-part mold which included 4 separate axe heads. Each mold required 60 pounds of Mar300 to fill. The mold features two large risers to promote feeding and a tapered gate attached to each axe head.

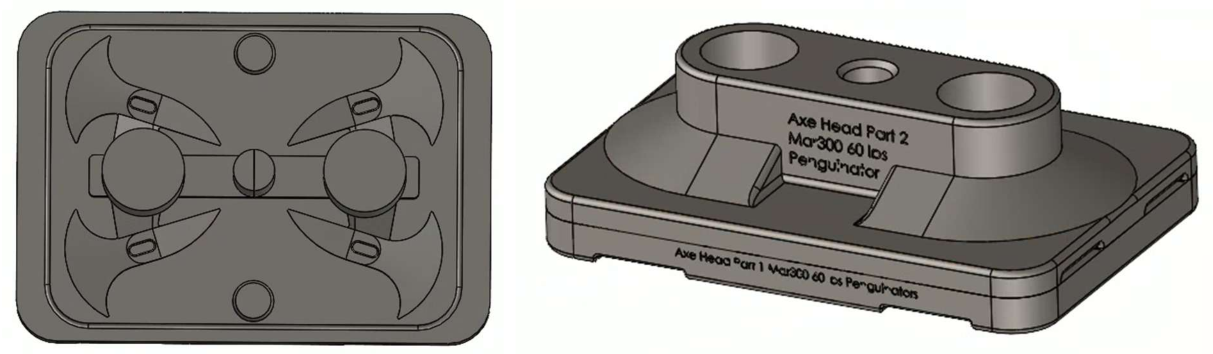


Figure 3: SolidWorks model of axe head mold

The goal of the simulation was to reduce as much porosity as possible to ensure the strength and quality of the axe. Several simulations were run for the axe head with different designs and riser sizes. The final design had almost showed almost no porosity left in the axe heads and the porosity that did show up was determined to be in a non-stress critical location. This can be seen in Figure 4.

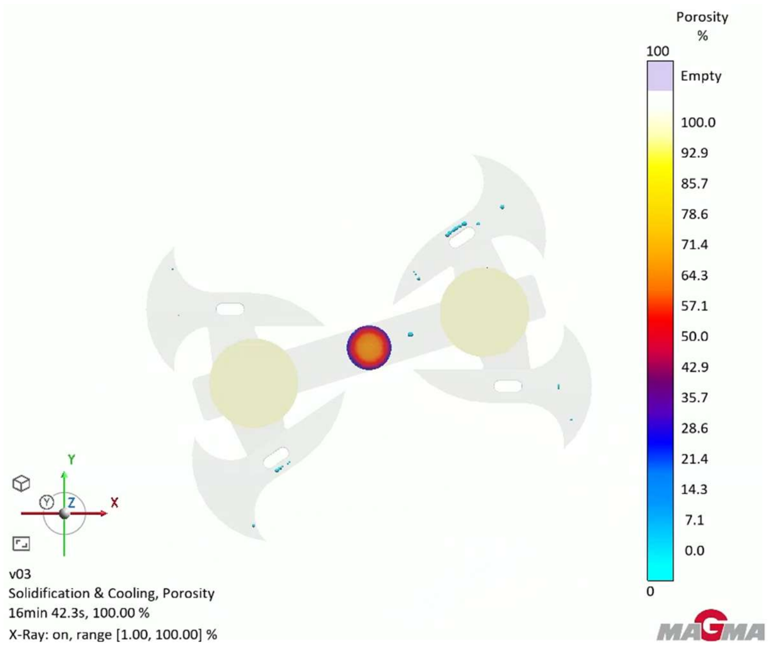


Figure 4: Axe head simulation results showing porosity

The hot spot fraction solid result from MagmaSoft (Figure 5) showed the risers were the last part of the mold to solidify and the blades were the first. This result shows the mold functioning as intended making sure the blades are fully fed until they freeze off.

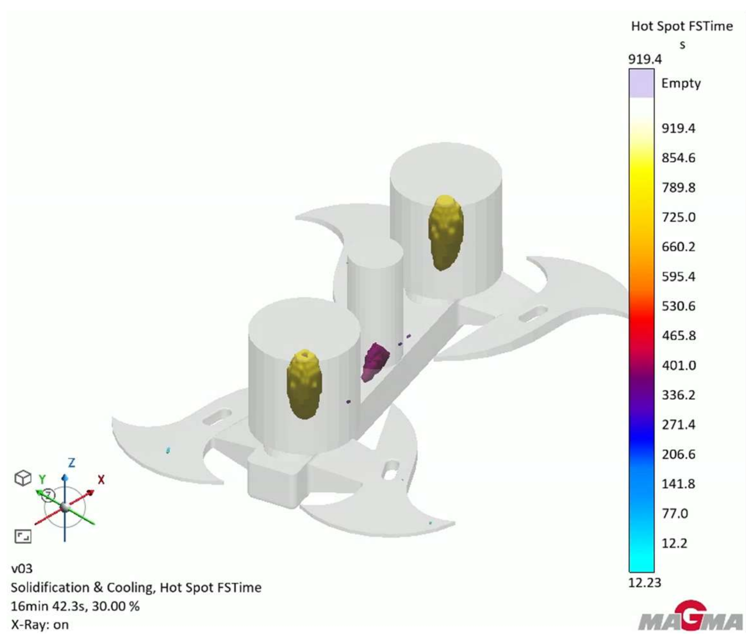


Figure 5: Axe head simulation results showing spot FS time

The tapered gates allow for directional solidification guaranteeing the axe heads are the first part to solidify in the gating system. This directional solidification can be seen below in Figure 6 where the axe heads are a cool dark color and the runner is shown as still red hot. This confirms the tapered gates worked. The molds were 3D printed and donated by Humtown Products.

Figure 6: Solidified axe heads on gating immediately after pouring

The Mar300 was heated to 3000°F before the pour. After successfully pouring two molds, eight axe heads were made. After the axe heads were poured and cut off the gating, an annealing step was required for 45 minutes at 1500°F before the handles were attached. For the steel and aluminum to bond successfully to each other, an interstitial silicon bronze layer was applied onto the axe heads before the handle was cast. Additionally, the axe head was designed with a slot, so the aluminum fills the slot and wraps around the axe head to mechanically secure the two parts.

The handle mold was designed as a three-part mold which cast one handle. Overcasting required the axe heads to be inserted before the pour to perform the overcasting. The handle acted as its own runner making sure all parts of the handle were filled. The design for the mold can be seen in Figure 7

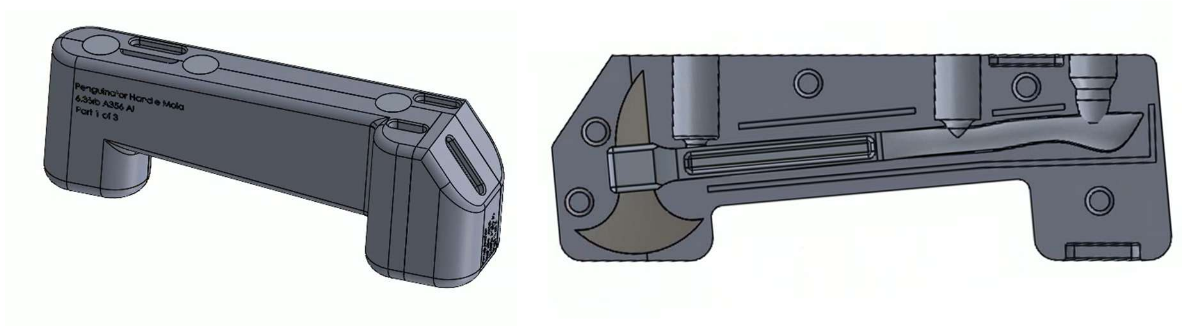


Figure 7: SolidWorks model of handle mold

Like the axe heads, the handle was run in MagmaSoft to reduce porosity. The simulation showed small amounts of porosity in the web of the I beam section. This is considered a low stress location and determined to have a negligible effect on the strength of the axe.

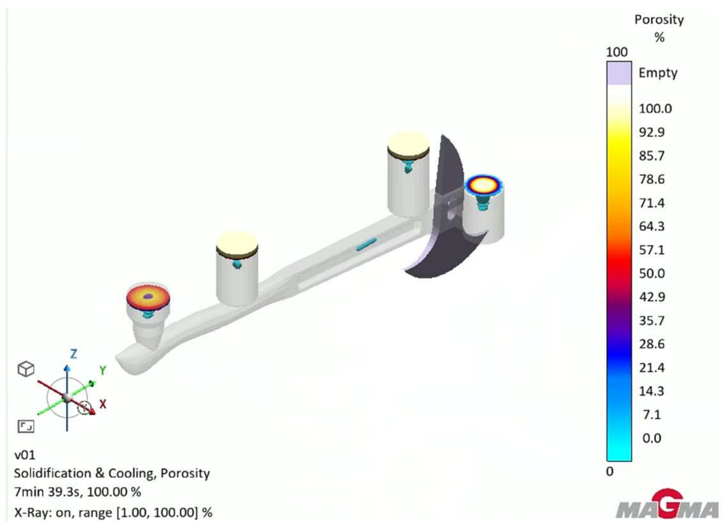


Figure 8: MagmaSoft simulation showing porosity

The robotic foundry at the YSU Excellence Training Center performed the overcasting for the handles. After cutting the handles from the gating, the axes were ready for the final finishing steps.

With the decision to design a dual material axe, the heat treatment needs to work for both materials. Mar300 has an initial annealing step that is 1500°F for 1 hour. This step will melt the aluminum handle and therefore must be done before the overcasting. After this step and the handle is overcast, both materials must be aged at 1000°F for 8 hours. A water quench was needed for the T6 heat treatment of the aluminum immediately following the aging process. Finally, the aluminum required a final tempering at 350°F for 10 hours. This ensures the steel is aged and the aluminum receives a proper T6 temper.

The axes had a significant amount of scale left on from the heat treatment seen in Figure 9. Flap discs on angle grinders were used to take this off.

Figure 9: Axes post heat treat

The final steps of the axe are inscribing the YSU Block Y design onto the axe with a laser engraver and applying the grip. The grip used was an 8-inch StickGrip X Series sports grip to contribute to the ergonomic feel of the handle.

Inspection and Testing Plan

A chemical analysis was performed before the axe heads were poured to ensure the quality of the Mar300 using a Thermo Scientific ARL OES Spectrometer. Below is Table 1 comparing the acceptable ranges for the chemistry of Mar300 and the results of from the spectrometer in percentage by weight.

Table 1: Chemical comparison of Mar300 and test results from spectrometer

	Fe	Co	Ni	Mo	Ti	Cr	Al	P	C	S
Mar300	Bal	7.0-9.0	17.0-19.0	4.5-5.2	0.3-1.2	0.5 Max	0.15 Max	0.03 Max	0.03 Max	0.01 Max
Test result	66.7	8.8	19.5	4.9	0.002	0.009	0.006	0.01	0.02	0.006

While the chemistry was slightly off from the material data set, the main characteristics of Mar300, the low carbon content and high nickel and cobalt contents were within range to get very similar materials, however slightly diminished.

Hardness testing was performed on the A356 handle and Mar300 steel to verify the heat treatment success. The axe head averaged a reading of 42 HRC, opposed to the expected 50. The hardness testing machine used was reading 3-4 HRC low when testing a calibration sample. This in combination with a slight mismatch of the chemistry is what the team believes is the reason for the low readings.

The A356 aluminum gave an average reading of 48 HB, this is within the range from literature of 40-70 HB however again, the machine was likely reading lower than reality.

These results trend lower than the results expected, however due to issues with equipment and the experimental nature of the heat treatment process outlined earlier, the heat treatment was still deemed to be a success.

Final Summary

The final weight of “The Penguinator” is 3.2 pounds. The final length of the axe is 25 inches. The materials used were Mar300 for the axe head, A356 for the handle, silica bronze for the interface layer and a StickGrip X Series for the grip. The combination of these materials and the processes described in this paper ensure a strong axe for competition. The ergonomic grip is designed for comfort and strength. The combination of aluminum and steel ensures the axe head is strong enough for hard hits and while the handle is long enough for the weapon to be wielded on horseback. This is done without the use of any fasteners, and the only non-cast part of the axe is the grip.

References

“Aluminum / Aluminum Casting UNS A03560 Alloy.” *AZoM*, 7 Sept. 2012, www.azom.com/article.aspx?ArticleID=6760.

Built with Storefront & WooCommerce. “Martinez Tools – Martinez Tool Company.” *Martineztools.com*, 2020, martineztools.com/.

Inc, Service Steel Aerospace. “Maraging 300 / VASCOMAX® 300 Steel Bar Rod Plate Sheet Billet, AMS 6514.” *Service Steel Aerospace Corporation*, 10 Dec. 2019, www.ssa-corp.com/en/maraging-300-AMS-6514.php.

“Maraging 300 Alloy Steel (UNS K93120).” *AZoM.com*, 6 Sept. 2012, www.azom.com/article.aspx?ArticleID=6751.

Acknowledgements

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With this support, we were able to enter the competition and have a great experience designing and manufacturing our entry. We would like to thank the YSU sculpture workshop for allowing us to use their dedicated work areas to process and finish our entry. We also thank YSU alumni Coleman Buchanon for his support and guidance. Lastly, we would like to thank the Office of the Dean and Student Government Association for funding our trip to the competition in Grand Rapids, Michigan.