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

University of Alabama at Birmingham – Blazing Steel

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ANDRITZ

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Page Burch, Russell Williams, Stephen Nabors

Introduction

Blazing Steel is comprised of two mechanical engineering senior undergraduate students, Abby and Kesy, and two materials engineering senior undergraduate students, Aliandra and Lauren. Of these members, only Aliandra has had any casting knowledge or experience. Stephen Williams, a 2015 UAB graduate and recent full-time staff member in UAB's foundry, has advised us in casting logistics and supporting our ideas. Through the experiences in this project, we now have a fundamental knowledge of sand casting and a respect for the manufacturing industry, which two of our team members will pursue as a career post-graduation.

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 goal of this project is to design and cast a historically accurate and functioning horseman's axe. Our aim was not to introduce groundbreaking techniques but instead to focus on the precision application of engineering knowledge and tools to create a high-quality, functional product. In the challenging, yet rewarding process, we have used Computer Aided Design, Computer Aided Manufacturing, and MagmaSoft for various aspects of the process. Applying casting techniques to a traditionally forged weapon has required planning, problem solving, and implementation of the iterative design process to produce a final axe that is functional and can withstand testing. This report outlines our design considerations and pathway to the final product. Attachment 1 contains all figures and tables. Attachment 2 contains the casting heat sheet and chemistries taken.

Our axe is sand cast, and all castings were poured in UAB's foundry using no-bake sand molds. Our steel alloy is a modified 4150 with a 0.25% vanadium addition as a grain refiner. The handle is ash. The axe has a weight of 2.02 lbs and a length of 29.5 inches.

Historical Considerations and Design Ideation

To start the design process, each team member found 1-2 examples to use as the bases for our horseman's axe. Each team member ranked different aspects of the designs in the matrix seen in Figure 1, and it was decided to choose the best factors of designs 1 and 2, highlighted green, to produce the lightest, most historically accurate, and functional axe possible. These designs are seen in Figure 2.

Design 1 was deemed to be the most historically accurate as it is a true historical example. Rather than purely recreating this example, we decided to add in aspects from design 2 to improve the functionality of the object, such as a pick to puncture armor rather than a small hammer that would require much force to dent it. The pick acts as a counterbalance to the blade and is a helpful addition to the axe to allow easier handling when wielding or repositioning the axe with one hand as intended.

Initially, we planned to adhere to the top spike that many horsemen's axes have, but then determined that it would be a stop of motion when swinging the axe from a horse. It would either stop the axe from swinging when hit from the side, or it would stop the blade from hitting the target altogether if the target was at a distance to hit the top curve of the blade. Due to these considerations, the top spike was removed and a center hole design for the head was chosen over an ornamental covering to have a stronger friction fit of the handle and to reduce weight, to aid in easier swinging.

An ash handle was chosen as many existing horseman's axes artifacts have ash handles. Ash was a strong and abundant wood native to Europe during the age of horseman's axes. Many horseman's axes also have languets to attach the head to the handle, protect the handle from shear stress during use, and act as deflection points to protect the handle from hits during combat. Most horsemen's axes showed the aesthetic and personality of their owners. Almost all axes used throughout history contain engraved, etched, or cast ornamental details denoting religious text, family sigils, and other cultural designs. In our axe, we have chosen to add a dragon and fire to represent the UAB Blaze mascot while retaining the menacing look of the axe.

The progression of our axe designs is seen in Figure 3. The first castable design (D1) was 2.54 pounds, 11.36 inches tall, and seen in the SolidWorks drawing in Figure 4. On a trip to New York City, Lauren went to the Metropolitan Museum of Art and saw the horseman's axe that was the team's main inspiration. It was then realized that D1 was much too large and heavy for the function of the long axe with a petite blade, as seen in Figure 5. The team decided then that we needed to edit the model to create a smaller, thinner, lighter blade with longer languets. This is the second castable design, D2. The measurements are seen in Figure 6. The third castable design, D3, has the same geometry as D2 but with the added design element.

Alloy and Heat Treatment

The alloy chosen is modified 4150 with a 0.25 wt% vanadium addition, with the compositional specifications seen in Table 1. For edge retention, a high carbon content was chosen. 4140 is a common alloy for axes due to its strength and impact resistance, so this was chosen as a starting point. From the 1st edition ASM Handbook Desk Edition, it was seen that after quenching and tempering, the hardness of 4140 was in a range of 30-52 with a tempering temperature range of 1000°F-400°F. As seen on numerous online websites and forums for performance axes, the edge hardness range should be 55-60 HRC. To encapsulate the strength of 4140 and obtain the hardness needed for our axe, 4150 was chosen for the base alloy. The extra carbon increases the hardness to a range of 56-60 with a tempering temperature range of 1000°F-400°F per the 2nd edition of the ASM Heat Treater's Guide.

There is a trade-off between hardness and ductility that must be considered. A hard alloy will offer excellent edge retention but could be brittle and crack with little force. The answer to this dilemma is the 0.25 wt% vanadium addition. Vanadium in steel refines the grain size, which produces more grain boundaries to impede dislocations, and it also produces very small carbides in the matrix that have the same effect. Only the latter is important for our purposes because our microstructure will be martensitic from quenching. This increases the fracture toughness of the steel, which is needed in the application of our axe. 0.25 wt% was chosen because it is in specification for S7 shock-resistant tool steel. This alloy was considered briefly, but it has more expensive alloying elements, is less machinable, which is unwanted for our desired quality finish, and its heat treatment can be unreliable with retained austenite to martensite conversion after tempering.

Segregation of carbon and chromium can occur in as-cast steels, but time spent above austenitizing temperature during heat treatment promotes the diffusion and homogeneity of the composition. The chosen heat treatment consists of an overtemper, two normalizes at 1600°F, austenitizing at 1555°F (above Ar3 on the Fe-C phase diagram), quenching in 11-second oil, tempering at 500°F, and finally air cooling. The two normalizes properly refined and created a homogeneous grain structure, the oil quenching produced a fully martensitic structure without the quench cracking commonly seen with water quenches, and the tempering created strength from the martensite.

To balance the tradeoff between ductility and hardness, the correct tempering temperature must be chosen. To determine this, an experiment was performed. Nine miniature axes were cast and heat treated but tempered at four different temperatures, 400°F, 600°F, 800°F, and 1000°F. The axes before sharpening are seen in Figure 7. Two axes were tempered at each temperature. One axe was cast with a steel chill on the blade to determine if this had a noticeable effect on performance. After sharpening, tests were performed on a wooden block, a 16-gauge piece of cold-rolled steel, an 8-gauge piece of cold-rolled steel, and finally a 1.5 inch rope to determine if the edge was retained after testing. Only the 1000°F temper had any noticeable blade deformation. So, more testing was done on a 1/4-inch cold rolled square bar, and a 4” hot rolled 4140 bar, and the 1.5 in diameter rope. Significant blade deformation occurred only on the 800°F temper, leaving 400°F and 600°F as options. A temperature of 500°F was chosen to reduce deformation of 600°F but avoid the potential brittleness of the 400°F.

To better characterize our chosen heat treatment, microscopy was performed at each tempering temperature and HRC data was collected. The HRC data is seen in Figure 8. Most performance axes seen online had a hardness of 55-60, so we wanted our chosen tempering temperatures to be roughly the same. The 500°F has an HRC of approximately 56. The microscopy of a 400°F, 600°F, and 800°F temper with 4% Nital etchant is seen in Figure 9. Because the carbon content is less than 0.06%, the microstructure exhibits a lathe structure, most evidently seen in the 400°F temper. It is clear, as expected, that the increased tempering temperature homogenizes the structure and decreases the needle-like lathes, to reduce distortion of the lattice and associated strain.

When aggressively testing these miniature axes, the goal was to test until failure. These axes were not designed to reduce stress concentrations, and the mode of failure was brittle fracture where the blade met the handle, as seen in Figure 10. While this stress concentration would not be in our final design, the shear stress on the head/languet area was emphasized. We decided to add a differential heat treatment to the axe to increase the ductility in the head/languet area, but not at the blade or pick. We wanted a considerable amount of ductility in the area, so a temperature of 950°F was chosen. The 950° temper for the languet/head area has an HRC of approximately 42.

Casting

The team chose to use sand casting as UAB's foundry has all the tools necessary to sand cast steel, such as a CNC machine and 3D printers for patterns, a no bake sand mixer, and a 120-lb induction furnace capable of melting steel. All compositions were made from 1005 steel punchings donated by our foundry partner, ANDRITZ, and internal returns from previous castings. To achieve the target alloy of Table 1, an excel was used to calculate the amount of alloy addition for each element, given the 100-lb heat amount and chemistries of the bulk steel melted. During the heat, chemistries were taken after the initial alloying elements were added to see if any other alloying was required, given inaccuracies in the melted steel compositions and recovery rates. If required, more alloy is then added before the pour. Samples were taken before and after the pour to inspect the change of composition due to varying elemental recovery rates.

For our first full-scale cast, the plan was to cast two of each design, D1, D2, and D3, and test their performance to ultimately choose the most impressive axe that withstood test conditions. We decided to cast with one furnace pour using a mother mold. This is because in the miniature axe experiment, 10 points of carbon burned off between the first and last axe poured. If a similar burnoff occurred for this full-scale cast, the results of the test could possibly be skewed. To create this mother mold, we made the six individual axe molds and attached them to a runner to connect each mold to a large sprue and pour cup. The gating system used to attach each axe to the runner is seen in Figure 11. A depiction of the mother mold internal setup is seen in Figure 12. This gating system was chosen because the head pressure of the tall sprue and the vertical orientation of the axe allows a vertical fill to reduce turbulence. The blade and pick ends solidify first, refining their grain size and increasing density.

When breaking open the 800 lb mold with chisels and sledgehammers, it was seen that the thinner designs, D2 and D3, did not cast. The in-gates into the languets and the bottom of the blade were not sufficient. The cast is seen in Figure 13. This was a blow to the team, as we were confident that we would use the thin blade design and now there was no way of comparing the performance of the different designs. So, we edited the gating system to have more ingates on the languets and blade, seen in Figure 14. We did another casting of the thin D2, and the molds successfully filled, although there was a CNC-caused shortening of one side of the pick. This meant another mold and casting of D2 was required. The MagmaSoft solidification simulations for the new gating for both D2 and D3 are seen in Figure 15. Both show the edge of the blade and pick with the first solidification, which is beneficial to reduce porosity. The MagmaSoft porosity simulations are seen in Figure 16. Due to database alloy constraints, we believe the simulation is not completely accurate. When cutting off the gating where it claims over 70% porosity, solid metal was in the casting.

Our final casting consisted of 3 D2 designs and 4 D3 designs. The process for our final casting is as follows:

1. Computer Aided Design: All 3D modeling was done in SolidWorks. We made the axe and used the wrap feature for the dragon and fire design. We used a 3D printed core box rather than CNCed to reduce time spent. We printed 3 core boxes to make many excess cores to account for the fragile shape possibly breaking. Due to the complex geometry in the design, draft could not be added to all areas of the design, so we decided to use a 5° tapered bit on the CNC machine to automatically add draft.

2. Computer Aided Manufacturing and CNC: Autodesk Fusion was used to create a step-by-step process to make the pattern and the gating system. To get the most precise and accurate pattern in the quickest completion time, several iterations of each step were run through Fusion. The initial step was the roughing, where a large portion of the 2 in sugar pine board was taken down and a rough shape of the pattern was made. The second step flattened the flat portion of the mold surrounding the pattern. This greatly reduced machine time, as a large flat bit could be used here rather than the fine detail bit. The third step added draft to the alignment pins. The fourth refined the pattern and added detail. A 1/32nd in radius tapered ball nose was used to add draft to the detail. These four steps were repeated for both the cope and drag. The CNC portion took roughly 8 hours to complete for each side before sanding and shellacking. A permanent mold was chosen to quickly make many molds. Sugar pine was used because it is easily machinable and tends not to splinter. Shellac was applied and sanded to fill any pores in the wood to improve the surface finish.

3. Preparing the molds: We used no bake sand molds made of 2-part epoxy binder and OK 85 sand. Sand was donated by ANDRITZ. Before each mold was made, a coating of mold release made of aluminum powder suspended in heptane and a layer of graphite powder was applied for easy sand removal. The mold boxes were carefully removed while the sand was still in a flexible state, then the cope and drag were assembled and allowed to fully set to allow better coping to reduce flashing. A core was used to make the hollow head of the axe and the languets. The core also acts as an alignment pin for each half of the axe and gives the central section of the mold support while casting. Pour cups were sanded on the closed molds to ensure no gapping, then the molds were opened, sprayed with compressed air, closed, and clamped. Tape was added to the sprue and vent to prevent potential contamination during movement. After placement on the sand bed, core paste was applied to the seam between the cope and drag on the outside of each mold to prevent runout while not adding a gap between molds from the thick paste. The tape was then

removed, respective pour cups were clued to their molds, and paper was taped on top of each pour cup to prevent contamination until the pour.

4. Pouring: The cast was successful! The heat sheet and all 3 chemistry results are seen in Attachment 2. Our melt was 100 lbs of bulk steel, graphite, FeMn, FeSi, FeCr, FeV, FeMo. After the first chemistry, 6 points of graphite and 15 points of FeMn were added. This was allowed to mix in, then Aluminum and Foundrisil were added as deoxidants. Once up to temperature of approximately 3050°F, the steel was poured. Our final chemistry was out of specification due to low manganese. The ideal diameter of the target composition and final compositions are 8.367 and 6.673, respectively. So our final hardenability was less than our target, but still well above the required hardenability for the axe. The calculation values, from ASTM A255, are seen in Tables 2 and 3.

Finishing

After casting and overtempering at 1200°F to soften the steel, we used an angle grinder to cut off some, but not all, of the gating. We left the bottom part that connects the languets and the side where the ingates are. This was to prevent warping from the languets leaning against the side of the furnace. Using a drill press, holes were made in the languets in the softened state. Once the initial heat treatment (overtempering at 1200°F, two normalizes at 1600°F, austenitizing at 1555°F, quenching in 11-second oil, tempering at 500°F, and finally air cooling) was completed, the gating was completely cut off. The differential heat treatment at 950°F was done on the languet/head area using 3 mat-pro torches while the blade rested in water and the pick was wrapped in wet cloth and covered with fiberglass insulation. This setup is seen in Figure 17. A thermocouple was clipped to the inside of the head/languet area to ensure accuracy of the heating, and color change was used to note when the languets reached 730°F, based on the colors in Figure 18. Note that color change could not be used for the head area because no color change is seen after 730°F.

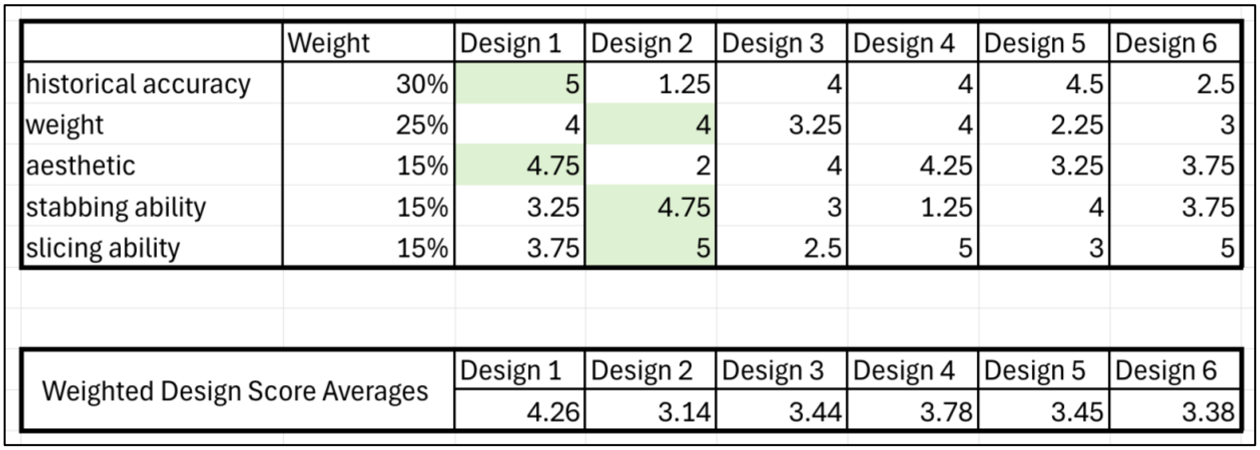
To sharpen the axe to have a perfectly uniform angle across the curved blade, Abby designed and 3D printed a jig to use on our grinder, seen in Figure 19. The head of the axe fits in a sleeve that contains a pin that fits in the holes of the jig, allowing circular motion of the axe around the central point of the diameter of the blade. One jig was made that worked for the 30° main bevel of the blade and for the 42° microbevel. This angle change was performed by unbolting and re-tightening the grinder and using an automatic angle finder. 10 grits of sandpaper were used, ranging from 36 to 2000, and an additional 6000 grit whetstone and leather strop were used to create the smoothest finish possible. Initially, a different grinder and jig was attempted, seen in Figure 20, but the motor in the top right caused interference of the languets that couldn't be overcome. To remove scale and rust buildup, the axe

To make the handle, a block of ash was bought and planed using an angled table saw. It was cut to have the most linear sections of grain in the vertical direction of the handle. It was then CNCed, using Fusion CAM, on each side using alignment pins in the board. The design of the handle is straight with an increasing taper at the top of the axe at the head portion. After sanding using 800 grit paper, the bottom of the handle was inserted from the top of the head, allowing the taper to be hammered in to give a friction fit. Using the drill press, holes in the languets and ash handle were drilled. Epoxy was placed in the holes, and Chicago screws were inserted to apply compressive force on each side of the languets. Red Loctite thread locker was used to prevent any vibration-caused loosening to occur.

Testing

After handles were attached using the friction fit to tester axes, D1 and D2 were tested on a wooden block, a 16-gauge piece of cold-rolled steel, an 8-gauge piece of cold-rolled steel, a 1.5 inch rope to test edge retention, then a 4” 4140 hot rolled bar to attempt failure. This was done before languets were compressed with Chicago screws, and they shifted slightly, but neither design broke. So, the D3 dragon design did not have a considerable amount of stress in the design. Because both axes were equal in performance, D3 was chosen to represent Blazing Steel due to its complex design. After connecting with the Chicago screws, the handle did break at that connection point after hitting aggressively on the 4” 4140 hot rolled bar. This is not the functional use of the axe though; it performed with little deformation on the steel plate, much like it would on armor.

Attachment 1: Figures and Tables



	Weight	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
historical accuracy	30%	5	1.25	4	4	4.5	2.5
weight	25%	4	4	3.25	4	2.25	3
aesthetic	15%	4.75	2	4	4.25	3.25	3.75
stabbing ability	15%	3.25	4.75	3	1.25	4	3.75
slicing ability	15%	3.75	5	2.5	5	3	5

Weighted Design Score Averages	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
	4.26	3.14	3.44	3.78	3.45	3.38

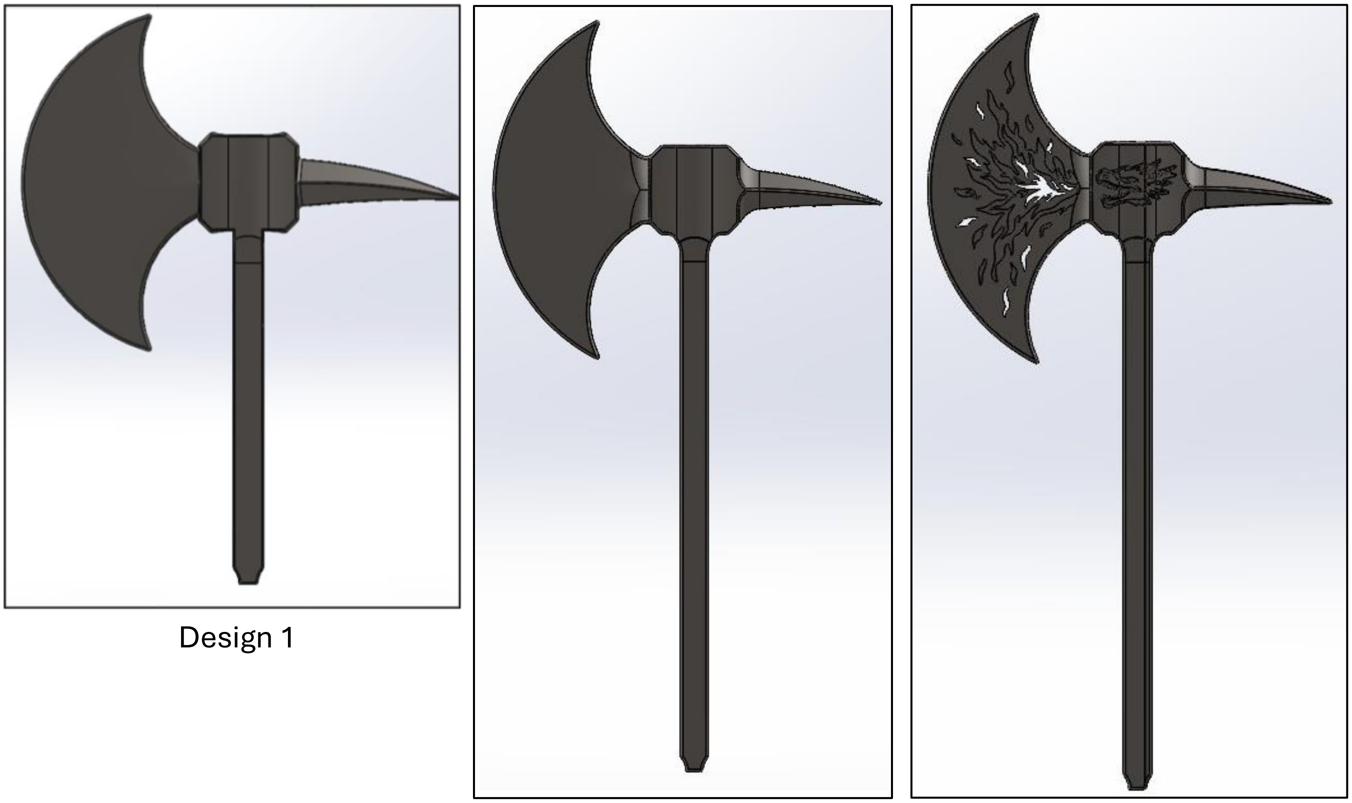
Figure 1: Ideation matrix used to determine design components

Design 1 - Reference

Design 2 - Reference

Figure 2: Main inspiration designs

Attachment 1: Figures and Tables



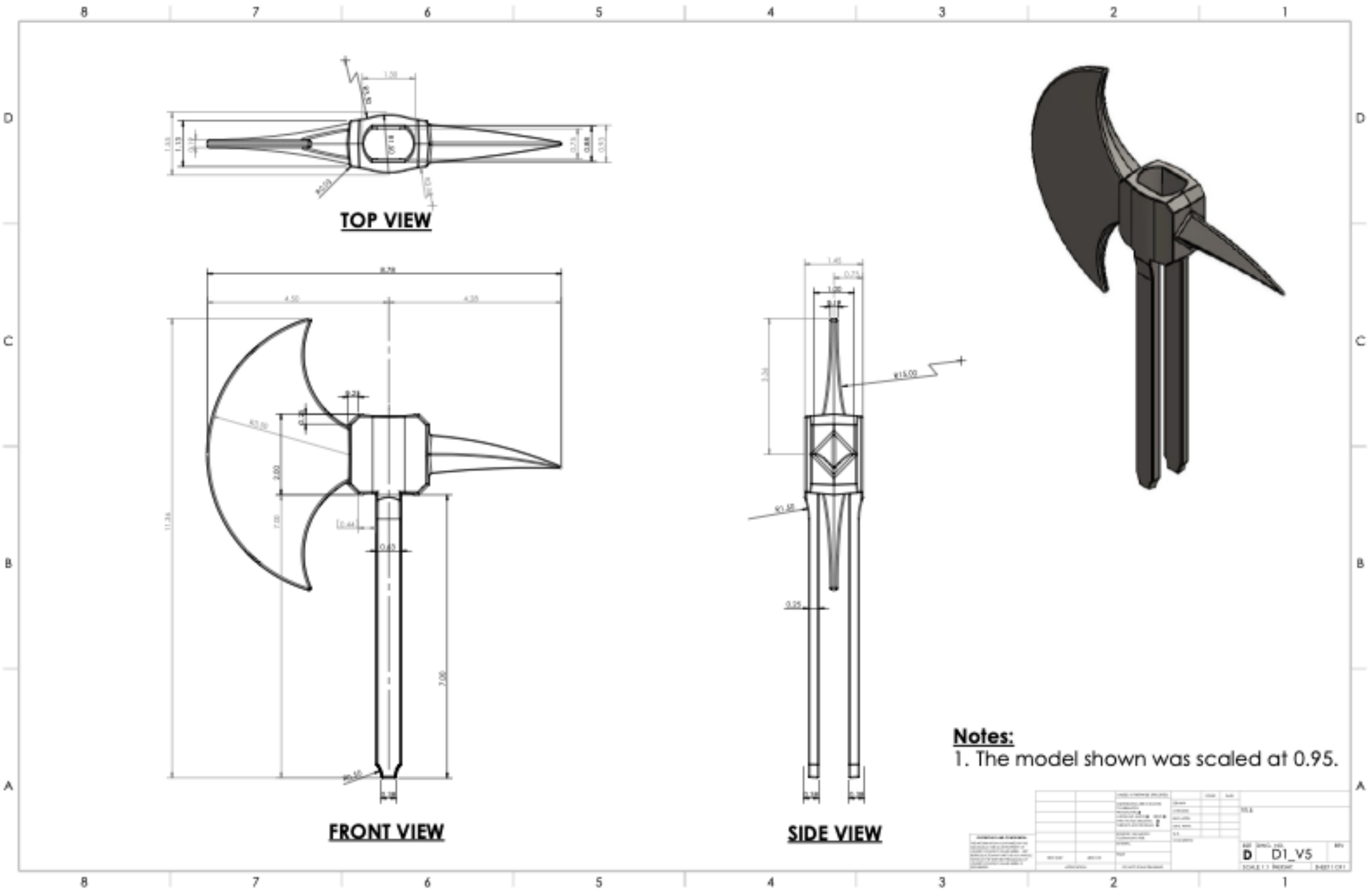
Design 1

Design 2

Design 3

Figure 3: Design progression

Attachment 1: Figures and Tables



Notes:
1. The model shown was scaled at 0.95.

Figure 4: Engineering drawing of D1

Attachment 1: Figures and Tables

Figure 5: in-person design inspiration

Attachment 1: Figures and Tables

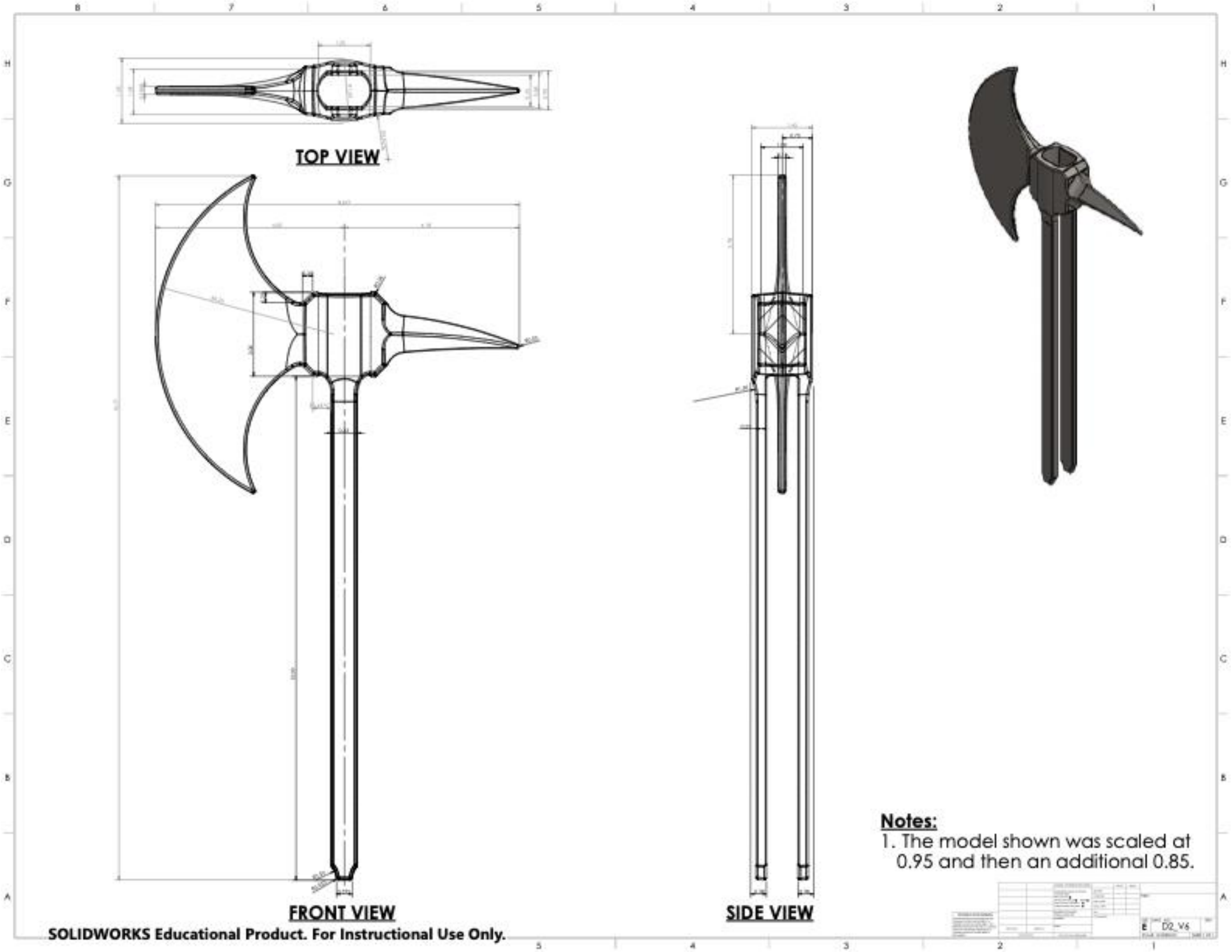


Figure 6: Engineering drawing of D2

Attachment 1: Figures and Tables

Table 1: Specification for our axe

	C	Si	Mn	Cr	Mo	V
Max	0.53	1.00	1.00	1.10	0.25	0.30
Target	0.50	0.60	0.88	1.00	0.25	0.25
Min	0.58	0.30	0.75	0.80	0.15	0.20

Figure 7: The miniature axes before sharpening

Attachment 1: Figures and Tables

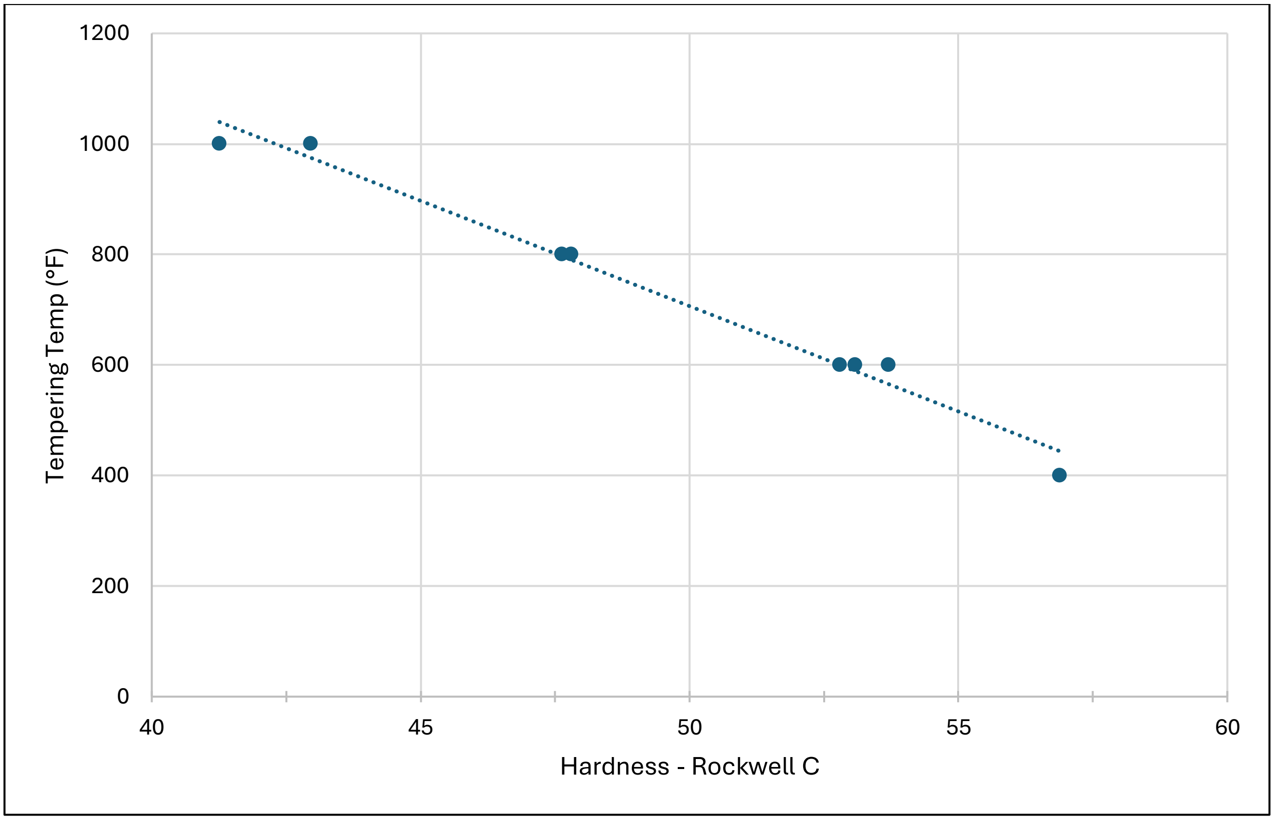
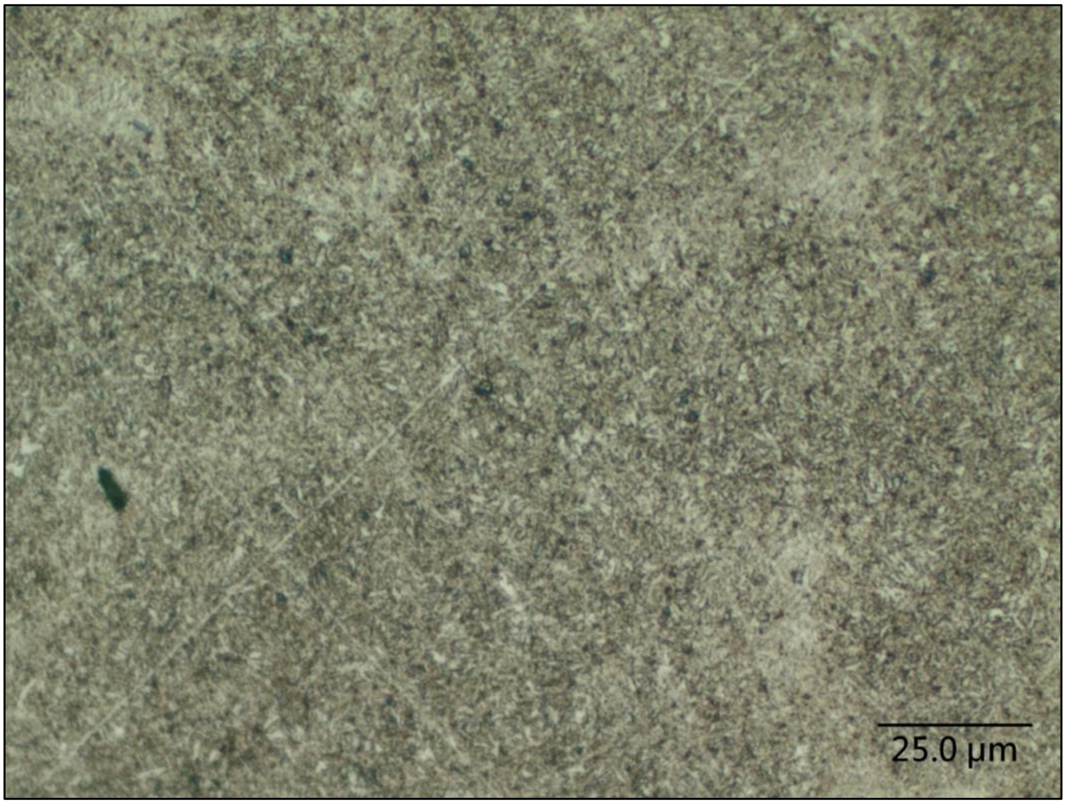
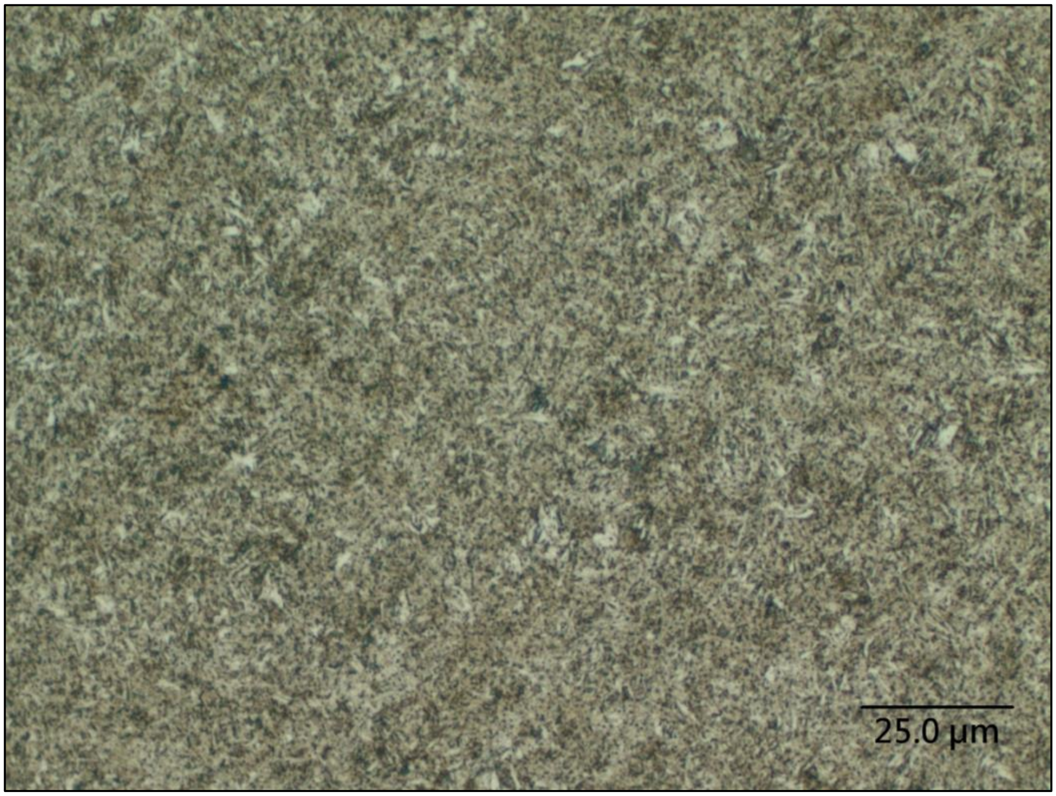


Figure 8: HRC data from the miniature axes

Attachment 1: Figures and Tables

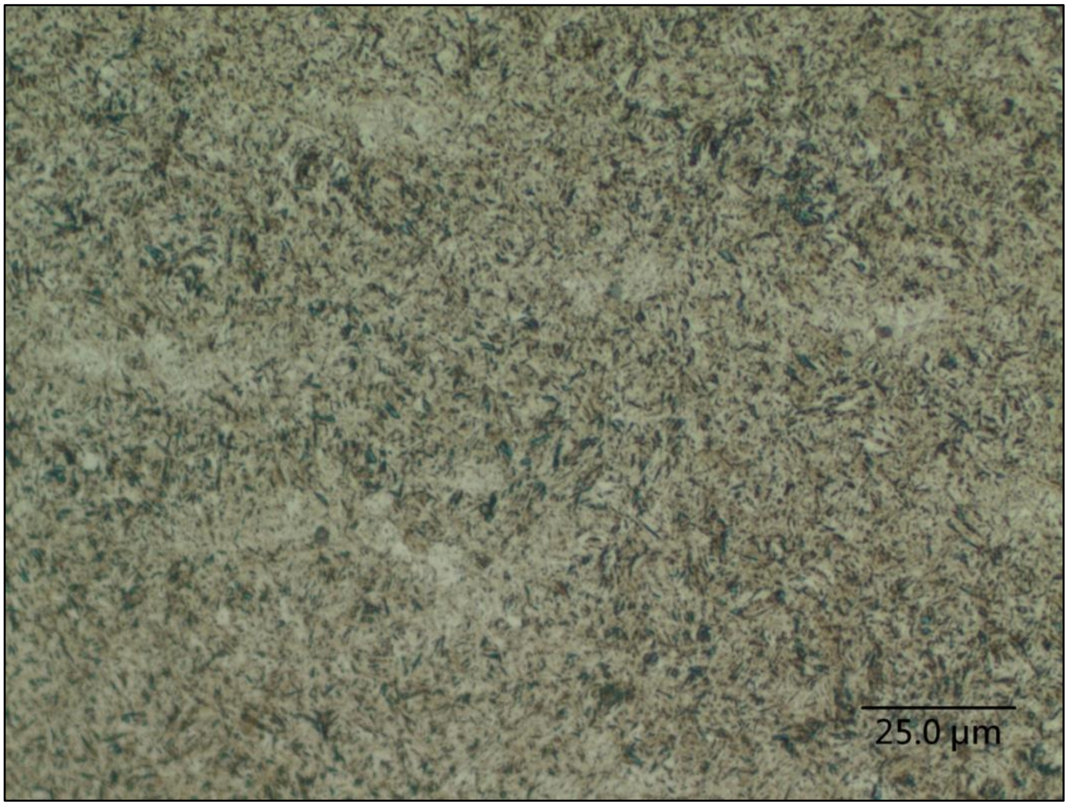


800°F temper at 50x magnification



600°F temper at 50x magnification

Attachment 1: Figures and Tables



400°F temper at 50x magnification

Figure 9: Microstructure of the 800, 7600, and 400°F tempers

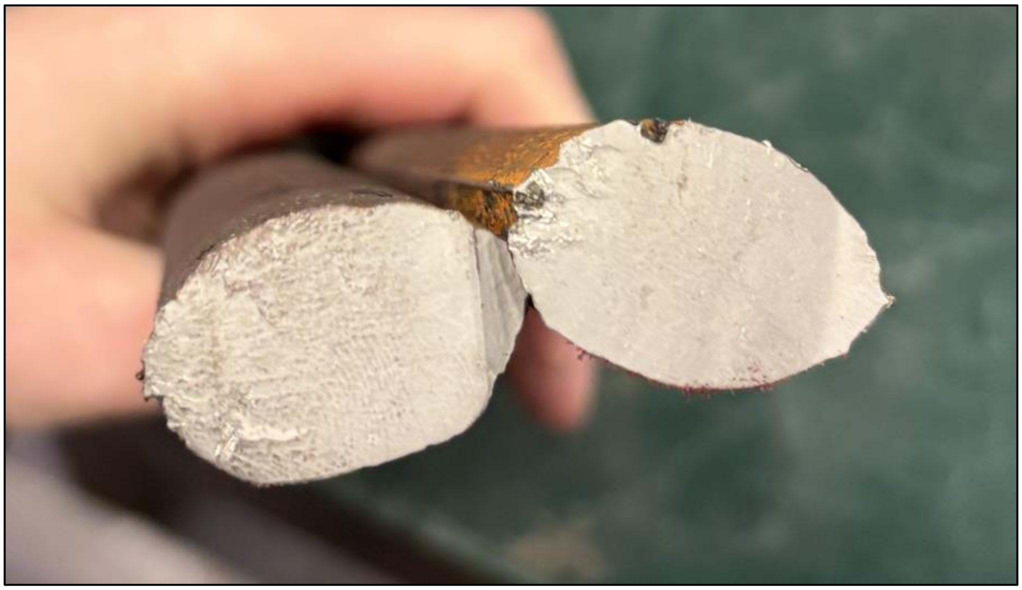


Figure 10: Brittle failure exhibited in the miniature axes

Attachment 1: Figures and Tables

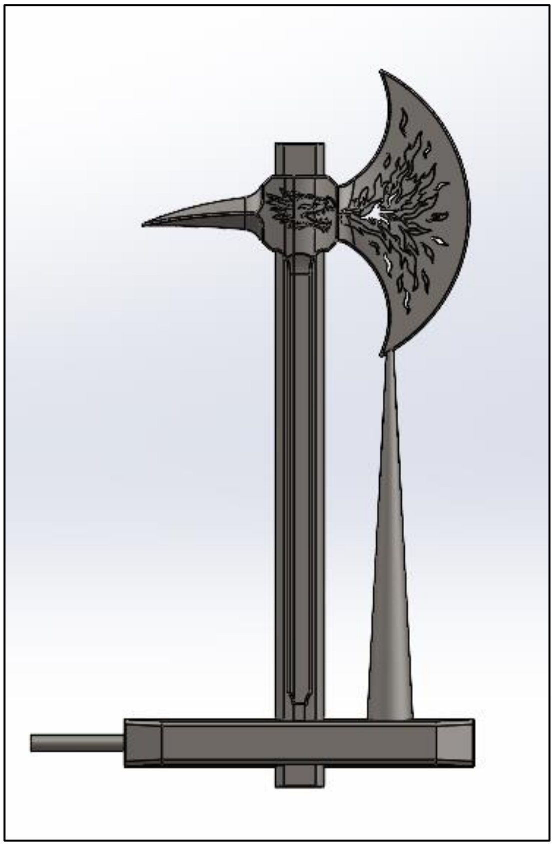


Figure 11: Failed Gating system

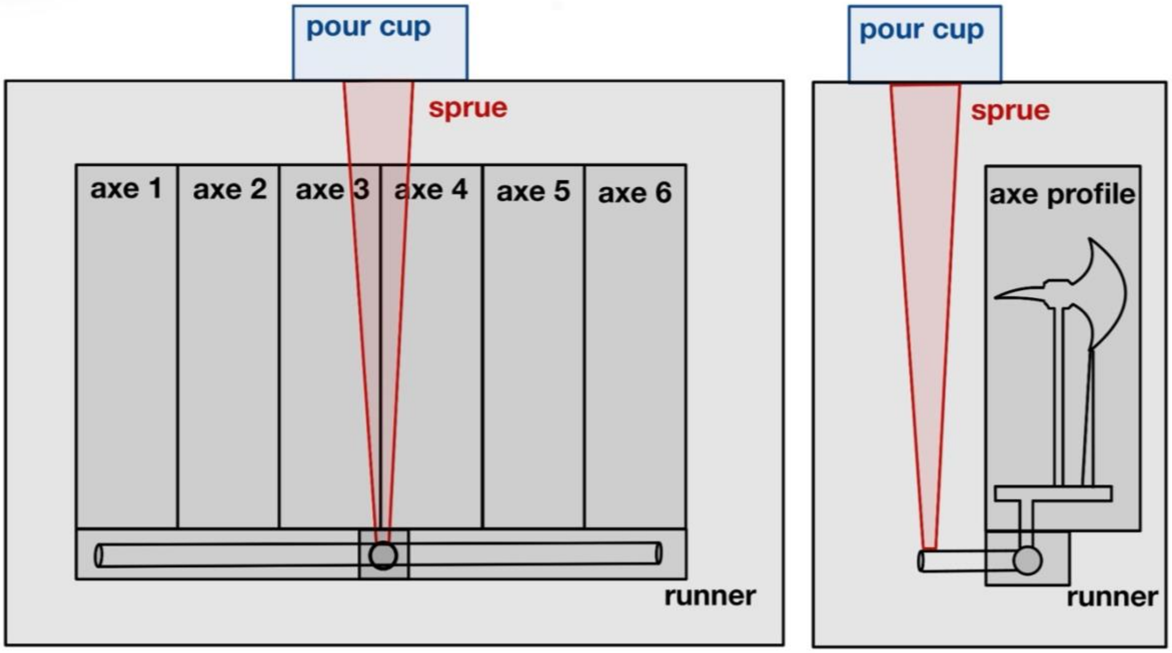


Figure 12: A depiction of the mothermold internals

Attachment 1: Figures and Tables

Figure 13: Mothermold casting

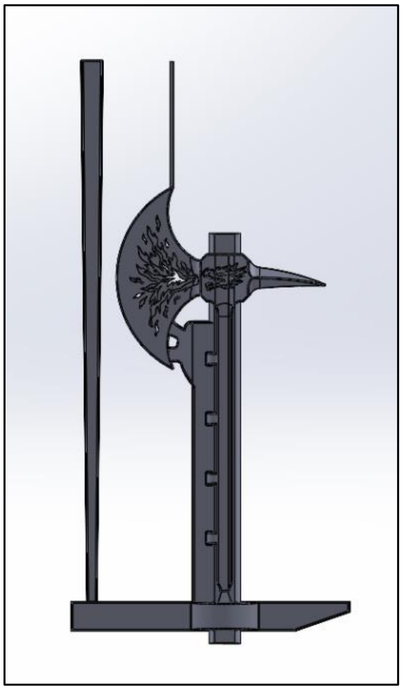
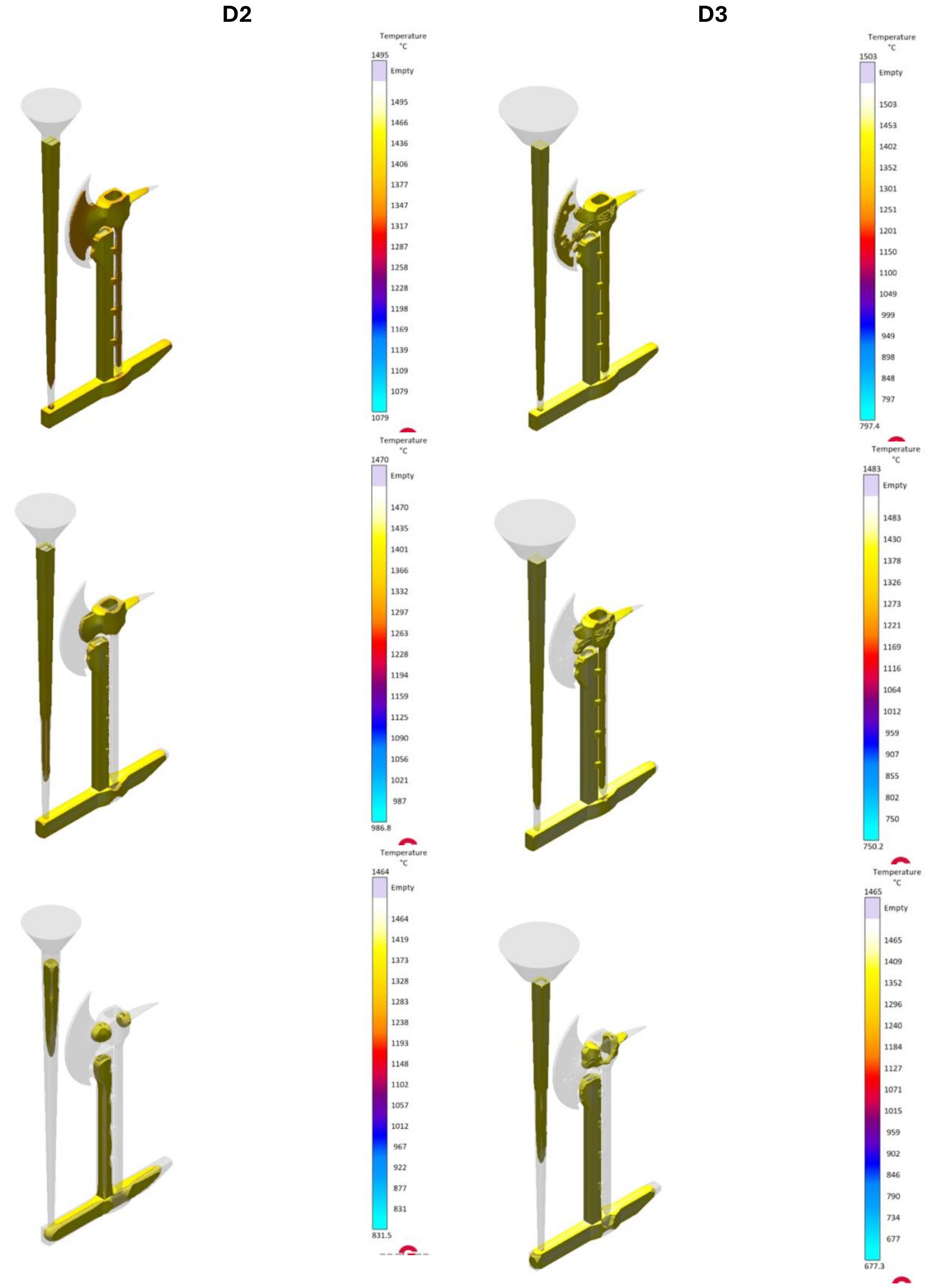


Figure 14: Updated gating for improved flow

Attachment 1: Figures and Tables


D2

D3

Figure 15: MagmaSoft solidification simulation

Attachment 1: Figures and Tables

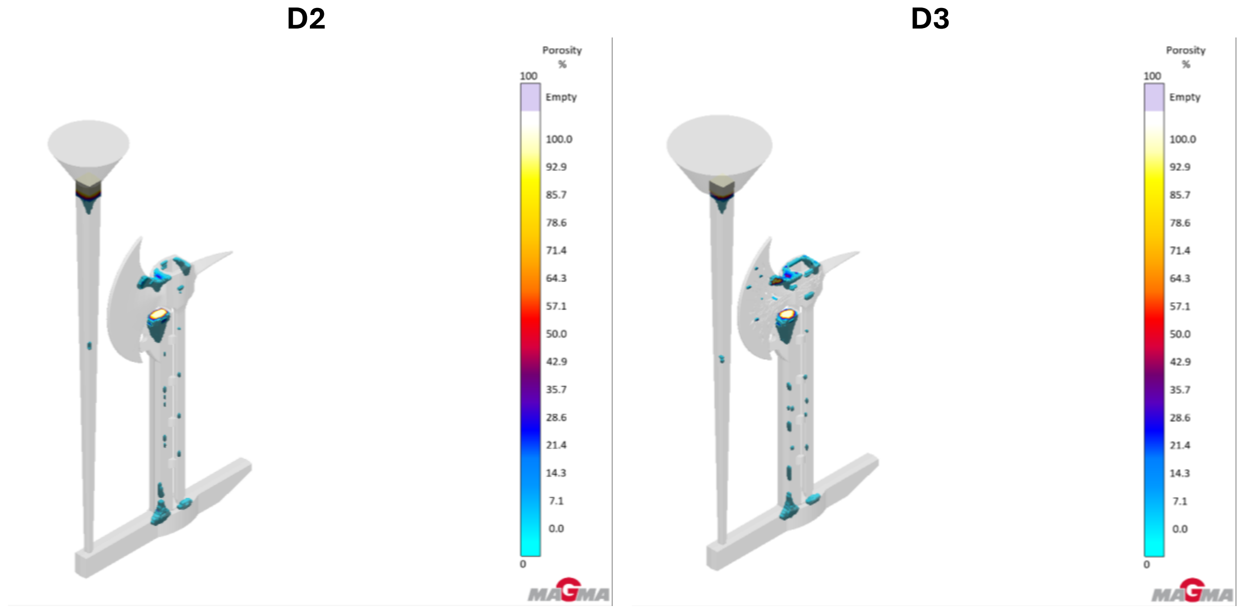


Figure 16: MagmaSoft porosity simulation

Tables 2 and 3: Ideal diameter calculations for the target and final compositions

	Target Composition		
	Wt%	Multiplying factor	Wt% * MF
C	0.50	0.238	0.119
Si	0.60	1.420	0.852
Mn	0.88	3.933	3.461
Cr	1.00	3.160	3.160
Mo	0.25	1.750	0.438
V	0.25	1.350	0.338
		Sum:	**8.367**

	Final Composition		
	Wt%	Multiplying factor	Wt% * MF
C	0.52	0.243	0.126
Si	0.41	1.287	0.528
Mn	0.65	3.167	2.056
Cr	1.00	3.160	3.160
Mo	0.26	1.780	0.463
V	0.25	1.350	0.338
		Sum:	**6.673**

Attachment 1: Figures and Tables

Figure 17: Differential heat treatment setup

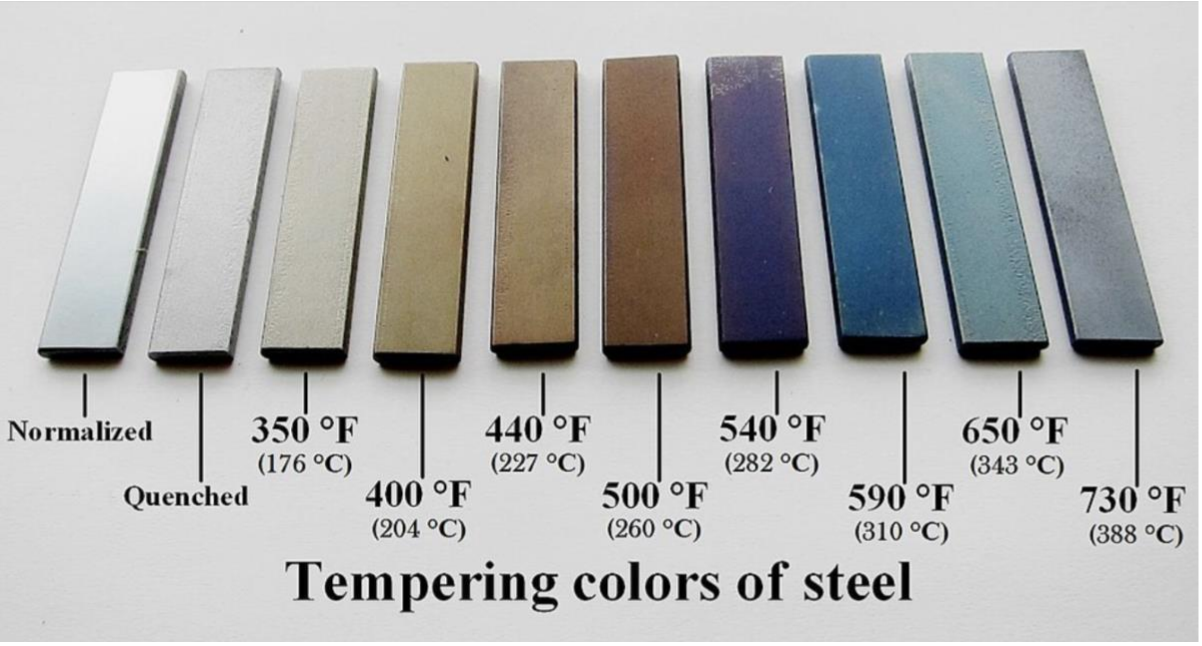


Figure 18: Colors of tempering steel, used on the langets

Attachment 1: Figures and Tables

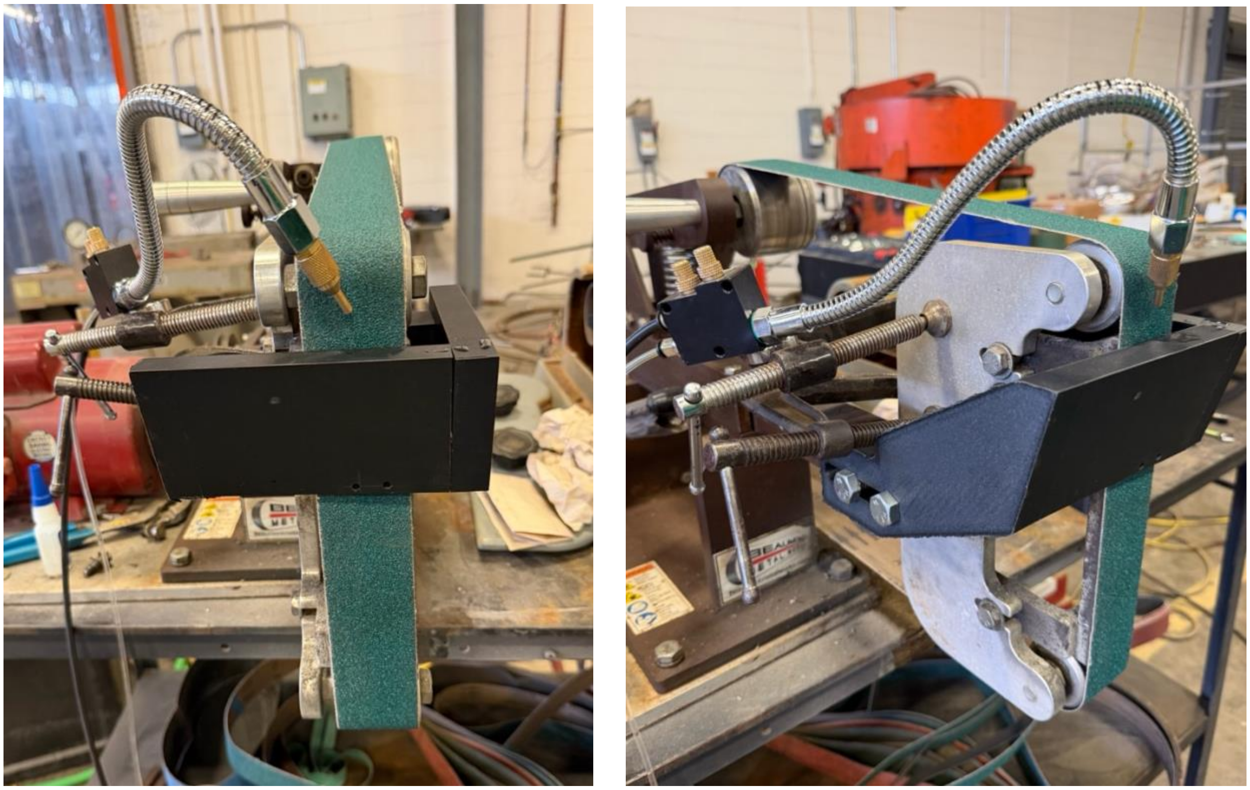


Figure 19: Grinder jig used to create uniform angle

Figure 20: Failed jig with motor interference

Heat Sheet - 4150 w/V

Date 3/22/26
Operator Stephen, Alixandra
Heat # 011
Alloy 4150

	C	Si	Mn	Cu	Cr	Ni	Mo	Mg	S	P	Al	Sn	B	Ti	V	CE
Max	0.53	1	1		1.1		0.25								0.3	
Target	0.5	0.6	0.88		1		0.25								0.25	
Min	0.48	0.3	0.75		0.8		0.15								0.2	

Time	Temp (°F)	C	Si	Mn	Cu	Cr	Ni	Mo	Mg	S	P	Al	Sn	B	Ti	V	CE
Melt in calc =>		.45	.45	0.98		1.00		.25								.25	
1010 am	Furnace On 11 Kw																
10:32		110 Kw															
10:47	All In																
10:53	2815																
10:54	2875			Sample 1													
	Sample 1	.46	.40	.76		1.04		.27								.26	
11:06		25.8 FeMn + 23.3 graphite															
11:12	3020	Al+Si added															
11:13	3036	pour #7															
11:16	3085	pour #2															
11:17	3034	chem #2				pour #1											
11:19	3094	pour #3															
11:20	3077	pour #4															
11:22	3105	pour #5															
11:23	3070	pour #6 ↔ chem #3															
	Sample 2	.52	.44	.68		1.00		.26		.009	.015	.005				.25	
	Sample 3	.51	.31	.61		0.99		.26		.008	.015	.002				.26	

Notes

Melt in Si target = .40 get ~20 points Si from foundrisil

↑ b/c get .20 from foundrsil

do a hardenability ideal diam calc to determine diff in harden from Mn difference

Charge Makeup

Material	Weight	lb/g
[illegible]		
009 returns	48.92	lb
1005 Andritz punchings	51.3	lb
graphite	68.1	g
FeMn	221.1	g
FeSi	90.8	g
FeCr	340.5	g
FeV	86.6	g
FeMo	90.1	g
Al	18.2	g
Foundrisil	136.2	g
FeMn	75.8	g
graphite	23.3	g
Total =>		

Deox / Ladle Adds	Weight	lb/g
Al (0.05)		
Foundrisil (0.3)		

Revision Date 12/14/25

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Sample Testing Chemical Results

4340 std

Sample ID :	**STD-BS60C-1**	**Alloy :**	**4340**	**Date:**	**3/22/2026**
Project :	**CIS AXE**	**Sample Type :**	**Disc**	**Operator:**	**SMW**
UAB Foundry-MASTER Grade :		**SAE J429 Grade 5**		**Program:**	**FE_100**

	Fe	C	Si	Mn	P	S	Cr	Mo
1	95.4	0.426	0.241	0.799	0.0107	0.0162	0.868	0.256
2	95.4	0.423	0.236	0.804	0.0095	0.0138	0.859	0.249
3	95.4	0.424	0.235	0.809	0.0108	0.0132	0.863	0.247
Ave	95.4	0.424	0.238	0.804	0.0103	0.0144	0.863	0.251

	Ni	Al	Co	Cu	Nb	Ti	V	W
1	1.69	0.0344	0.0143	0.147	0.0014	0.0008	0.0019	0.0094
2	1.70	0.0333	0.0125	0.150	< 0.0010	0.0009	0.0029	0.0091
3	1.70	0.0331	0.0111	0.147	0.0011	0.0008	0.0020	0.0059
Ave	1.70	0.0336	0.0126	0.148	0.0011	0.0008	0.0023	0.0081

	Pb	Sn	B	Ca	Zr	Zn	Bi	As
1	< 0.0010	0.0110	0.00105	0.0009	0.0032	0.0025	0.0023	0.0076
2	< 0.0010	0.0096	<0.00010	0.0007	0.0032	0.0019	0.0019	0.0075
3	< 0.0010	0.0083	<0.00010	0.0008	0.0032	0.0017	0.0019	0.0068
Ave	< 0.0010	0.0096	0.00036	0.0008	0.0032	0.0020	0.0020	0.0073

	Se	Sb	Ta
1	0.0061	0.0024	< 0.0050
2	0.0072	< 0.0020	< 0.0050
3	0.0066	< 0.0020	0.0062
Ave	0.0066	< 0.0020	< 0.0050

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Sample Testing Chemical Results

initial chem check

Sample ID : 011-Sample1 **Alloy :** 4150 **Date:** 3/22/2026

Project : CIS AXE **Sample Type :** Disc **Operator:** SMW

UAB Foundry-MASTER Grade : SAE J429 Grade 5 **Program:** FE_100

	Fe	C	Si	Mn	P	S	Cr	Mo
1	96.6	0.465	0.401	0.756	0.0158	0.0081	1.04	0.268
2	96.6	0.467	0.399	0.758	0.0153	0.0115	1.03	0.269
3	96.6	0.470	0.400	0.764	0.0163	0.0093	1.03	0.270
Ave	96.6	0.467	0.400	0.759	0.0158	0.0096	1.04	0.269

	Ni	Al	Co	Cu	Nb	Ti	V	W
1	0.0355	0.0051	0.0050	0.0418	0.0061	< 0.0005	0.262	0.0211
2	0.0356	0.0045	0.0031	0.0436	0.0059	< 0.0005	0.263	0.0230
3	0.0372	0.0048	< 0.0010	0.0471	0.0056	< 0.0005	0.265	0.0228
Ave	0.0361	0.0048	0.0030	0.0442	0.0059	< 0.0005	0.264	0.0223

	Pb	Sn	B	Ca	Zr	Zn	Bi	As
1	0.0029	< 0.0010	<0.00010	< 0.0005	0.0041	0.0057	0.0070	0.0029
2	0.0035	< 0.0010	<0.00010	< 0.0005	0.0040	0.0050	0.0074	0.0040
3	0.0035	0.0020	<0.00010	< 0.0005	0.0044	0.0054	0.0058	0.0055
Ave	0.0033	< 0.0010	<0.00010	< 0.0005	0.0042	0.0054	0.0068	0.0041

	Se	Sb	Ta
1	0.0073	< 0.0020	0.0099
2	0.0070	< 0.0020	0.0125
3	0.0076	< 0.0020	0.0136
Ave	0.0073	< 0.0020	0.0120

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Sample Testing Chemical Results

after # 2

Sample ID : 011-Sample2 **Alloy :** 4150 **Date:** 3/22/2026

Project : CIS AXE **Sample Type :** Disc **Operator:** SMW

UAB Foundry-MASTER Grade : SAE J429 Grade 5 **Program:** FE_100

	Fe	C	Si	Mn	P	S	Cr	Mo
1	96.6	0.531	0.449	0.654	0.0148	0.0093	1.01	0.265
2	96.6	0.519	0.436	0.669	0.0145	0.0099	1.00	0.263
3	96.6	0.523	0.448	0.667	0.0151	0.0089	1.01	0.265
4	96.6	0.526	0.439	0.679	0.0149	0.0076	1.00	0.266
Ave	96.6	0.525	0.443	0.667	0.0149	0.0089	1.00	0.265

	Ni	Al	Co	Cu	Nb	Ti	V	W
1	0.0325	0.0063	< 0.0010	0.0425	0.0057	< 0.0005	0.254	0.0069
2	0.0365	0.0064	< 0.0010	0.0427	0.0051	< 0.0005	0.257	0.0054
3	0.0360	0.0052	0.0014	0.0422	0.0056	< 0.0005	0.256	0.0065
4	0.0287	0.0049	< 0.0010	0.0439	0.0053	< 0.0005	0.259	0.0079
Ave	0.0334	0.0057	0.0010	0.0428	0.0054	< 0.0005	0.256	0.0067

	Pb	Sn	B	Ca	Zr	Zn	Bi	As
1	< 0.0010	0.0019	<0.00010	< 0.0005	0.0035	0.0041	0.0020	0.0028
2	< 0.0010	0.0025	<0.00010	< 0.0005	0.0034	0.0040	0.0017	0.0017
3	< 0.0010	< 0.0010	0.00156	< 0.0005	0.0036	0.0043	0.0019	0.0028
4	< 0.0010	0.0015	0.00077	< 0.0005	0.0039	0.0043	0.0024	0.0023
Ave	< 0.0010	0.0016	0.00058	< 0.0005	0.0036	0.0042	0.0020	0.0024

	Se	Sb	Ta
1	0.0057	< 0.0020	0.0108
2	0.0054	< 0.0020	0.0107
3	0.0052	< 0.0020	0.0102
4	0.0052	< 0.0020	0.0142
Ave	0.0054	< 0.0020	0.0115

2
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Sample Testing Chemical Results

before #6

Sample ID : 011-Sample3 **Alloy :** 4150 **Date:** 3/22/2026

Project : CIS AXE **Sample Type :** Disc **Operator:** SMW

UAB Foundry-MASTER Grade : SAE J429 Grade 5 **Program:** FE_100

	Fe	C	Si	Mn	P	S	Cr	Mo
1	96.8	0.519	0.378	0.607	0.0160	0.0088	0.991	0.264
2	96.8	0.510	0.369	0.613	0.0151	0.0076	0.990	0.261
3	96.8	0.508	0.372	0.622	0.0157	0.0076	1.00	0.262
Ave	96.8	0.512	0.373	0.614	0.0156	0.0080	0.994	0.262

	Ni	Al	Co	Cu	Nb	Ti	V	W
1	0.0354	0.0028	0.0066	0.0429	0.0050	< 0.0005	0.257	< 0.0050
2	0.0362	0.0026	0.0013	0.0413	0.0048	< 0.0005	0.256	< 0.0050
3	0.0320	0.0024	0.0021	0.0435	0.0049	< 0.0005	0.261	< 0.0050
Ave	0.0345	0.0026	0.0033	0.0426	0.0049	< 0.0005	0.258	< 0.0050

	Pb	Sn	B	Ca	Zr	Zn	Bi	As
1	< 0.0010	< 0.0010	<0.00010	< 0.0005	0.0038	0.0036	0.0018	0.0024
2	< 0.0010	0.0012	<0.00010	< 0.0005	0.0042	0.0032	0.0015	0.0032
3	< 0.0010	0.0023	0.00010	< 0.0005	0.0042	0.0030	0.0020	0.0024
Ave	< 0.0010	0.0011	<0.00010	< 0.0005	0.0041	0.0032	0.0018	0.0027

	Se	Sb	Ta
1	0.0042	< 0.0020	0.0086
2	0.0049	< 0.0020	0.0096
3	0.0060	< 0.0020	0.0125
Ave	0.0050	< 0.0020	0.0102