Steel Viking Axe

Submitted to

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This paper will discuss the design and process used for the making of a steel Viking axe. This axe was made by Texas State University students and our sponsor, American Foundry Group Inc. We will discuss our reasoning behind our design, the materials selected, and the modeling process used.

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Acknowledgments

We would like to express our most sincere appreciation to Able Ardis of American Foundry Group Inc. for his support, guidance, knowledge, and patience in aiding us with our project. His willingness to give his time and advice so generously has been very much appreciated and beneficial in manufacturing our Viking Axe.

Body

We designed our axe to be a bearded axe body style with a Mammen style surface. We also included a smaller blade on the back side of the axe for balance and to add robustness to the weapon. The Vikings depended heavily on their axe. It was considered more than just a weapon, it was their most valuable tool. The bearded body style is iconic to the Viking Age because it was such a versatile axe. Many Vikings used axes because they were less expensive than a sword and more importantly they had more than one purpose. The axe was used in a variety of ways such as building a house, ship or boat, on smaller tasks on a farm, for hunting, and even in combat.

This bearded axe style was common among the Vikings because it could be wielded in battle with more mobility than other styles. This style can be defined by the long blade edge and the hook behind the blade. The lower portion of an axe is called the "beard" and the cutting edge of the bearded axe extends below the width of the butt to provide a wide cutting surface while keeping the overall weight of the axe low. This hook would allow for the Vikings to pull weapons out of the opponent's hand, or hook the blade over the enemy's shoulder, shield, or ankle and bring them down in one motion.

The Mammen style is iconic due to the engravings on the surface. Some Vikings would add these into their axe to show their wealth while some patterns would symbolize special meanings. We engraved a bobcat to represent Texas State University, as well as embellishment around the blade and down the handle. We also added a diamond rib that follows the curve of the blades on both sides. This provides strength to the cutting blade. During research, we found that while axes are being forged, the blade end is split while another piece of material is wedged into the split and then hammered together. Doing this gives the axe the reinforced diamond shape toward the end of the blade. We included this shape into our cast axe blade to provide strength and reinforce the cutting edge.

During the concept selection phase of our design process, we concluded two different designs for our axe head. We originally had a diamond rib which was much more severe than the later design. We decided to change the design because when analyzed with MagmaSoft, it was brought to our attention that there would be an alarming amount of shrinkage in that area. We narrowed down the selected areas until MagmaSoft simulation was displaying shrinkage values that were not concerning (Figure 1, 2). Moving forward we acknowledged the minimal shrinkage that still existed in the casting by so adding insulation around the thinner sections. To minimize this even more, our sponsor blew air on the thicker ribbed sections furthest away from the tree during the solidification. In our second design, we changed the blade tip to a 25˚ angle. This angle was chosen because it would be strong enough for splitting wood and other various materials.

We had the choice to use 440C stainless steel and D2 steel. We choose D2 Steel to be used for our axe head. D2 steel is air hardening, high-carbon, high-chromium tool steel. The chemistry of the metal is attached below (Figure 3). This material was chosen because of the high hardness, 55 - 62 HRC, wear and abrasion resistant properties. This material was heat treatable, which was a characteristic we desired for our axe head. D2 is a common steel among knives because of the ability to retain an edge. Knowing that gave us more of an incentive to choose D2 over 440C. In conclusion, D2 steel has high abrasion resistance, which means that it would be tougher to sharpen but its edge would hold much longer.

Our sponsor Able Ardis works at American Foundry Group which is where the casting process was done. We chose to use investment casting as our process because of the unique shape and attention to detail. We strongly believed that investment casting was going to be our best option and most efficient in terms of yielding a completely defectless casting.

Our group decided to create the axe head in Creo Parametric 5.0.0. Once we finished the design in Creo we then sent the step files to Abel so that he could run it through MagmaSoft to conduct a solidification analysis. In this stage of the competition, we were able to see a simulation of how the axe would act during the solidification process. With this software, we were able to see areas of shrinkage, the mesh analysis, temperatures at all the nodes when it was poured and how different areas of insulation would help the casting solidify (Figure 4, 5, 6.1-6.4, Video Fraction Liquid). We had originally attached two axe heads to the same tree but later changed our design to be a single blade per tree due to the uncertainty of the axe being cast. We did not want to risk failure to both axes in the same pour.

Once our team was satisfied with the design and solidification analysis we proceeded with getting a third party to 3D print our investment pattern (Figure 7). On the pattern, we included the engravings so that they would be included on the casting and we would not have to machine them in after. Doing so would add a wasted process in our overall manufacturing process. Moving forward, it was time to build the dip shell that would surround the wax (Figure 8). We had the 3D wax blade connected to the tree in three places. We chose to do it this way because it allowed for the best flow during the pouring process and to ensure that the top part of the axe would fill completely. Once the wax blade was connected to the tree, the investment coating was added. Our next step was to melt the wax out of the shell, pour the casting, and lastly heat treat and sharpen. Our sponsor poured the axe blade out of our selected material, D2 Steel (Figure 9). The heat treatment consisted of heating under an Endothermic gas with a 1.00 carbon set point. The axe was heated up to up to 1850˚ F for two and one half hours, forced air quenched, reheated to 925˚ F for two and one half hours, forced air quenced again, and then reheated again at 950˚ F for two and one half hours. For the sharpening process, we had a 3rd party sharpen the axe blade for us. We wanted the blade to be held at a 25˚ angle to keep with our design of the tip while also not getting the blade too hot while it was being sharpened. If the blade got too hot while being sharpened it would weaken the structure of the steel, resulting it to be more brittle.

Our last step was to attach the handle to the axe. Our original plan was to purchase a pre-made handle, but we ran into a problem that the premade handles would not fit the eye of our axe. We then decided to use a straight circular bar of wood and shape the end to fit our eye. To do this our sponsor used a CNC mill to cut out the proper size and shape for the handle. We also added engravings on to the handle to complement the ones on the axe blade. For a final touch, our sponsor oiled the handle(Figure 10). Our axe head weighs 3.32 lbs with a cutting blade of 7in and our handle measures 30in.

Conclusion

We believe that our axe will hold up in both sharpness and durability. D2 steel hardness will hold the edge of the blade while the geometry and added heat treatment will reinforce the durability and strength of our axe. Due to the design and processes used we believe that our axe will exceed our project requirements.

Photos

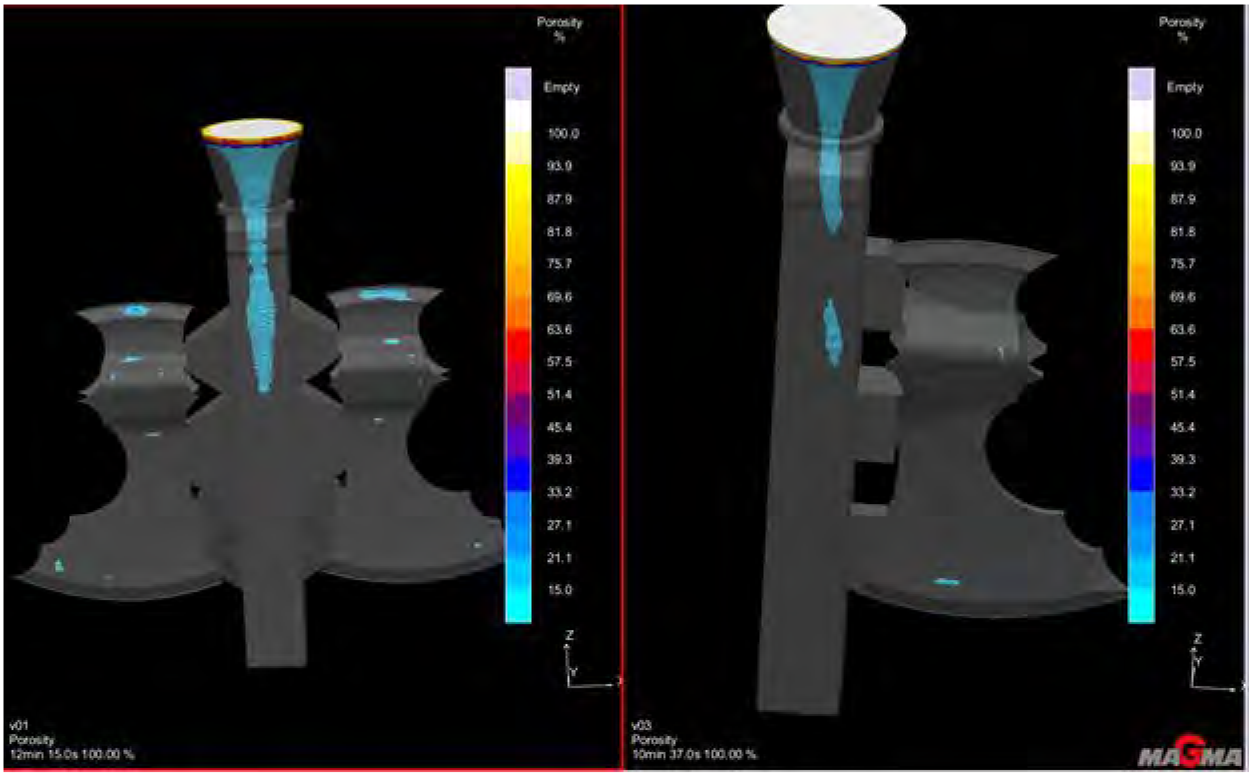

Figure 1

This is a screenshot from MagmaSoft that shows the porosity after solidification.

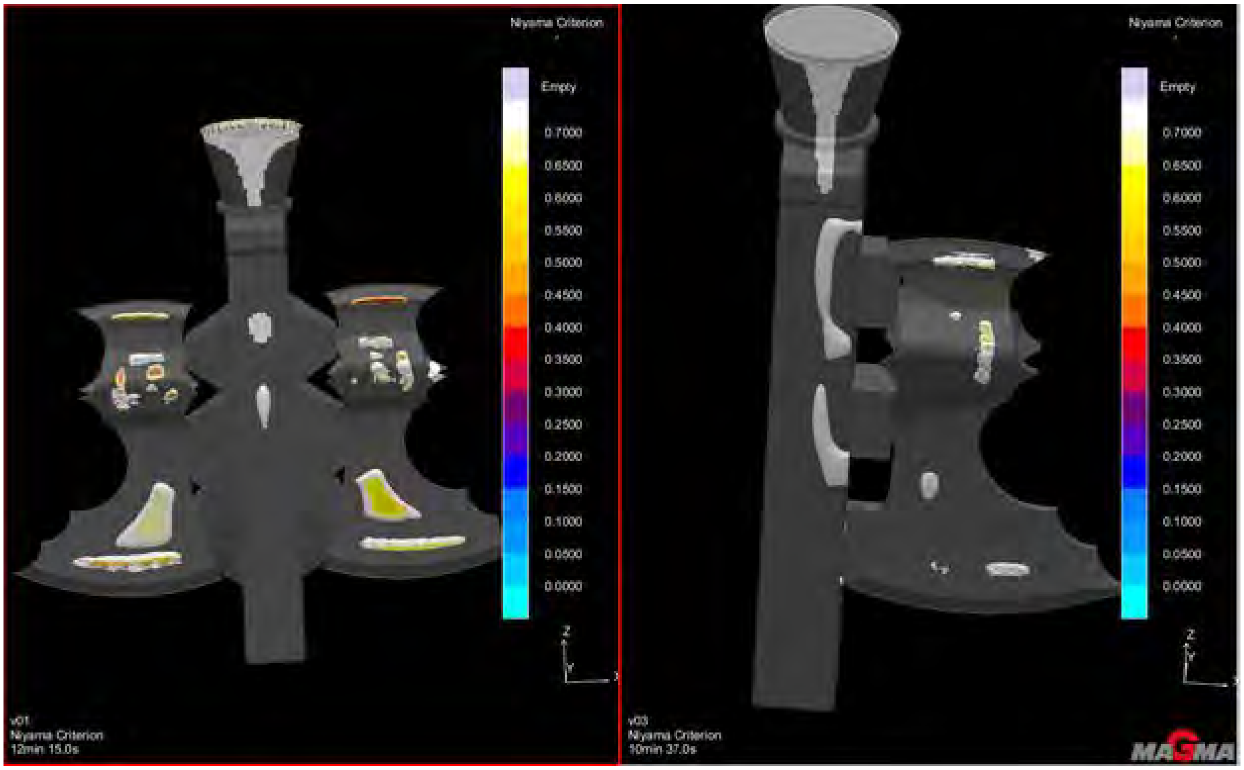

Figure 2

This is a screenshot from MagmaSoft that shows the Niyama Criterion after solidification.

360565

AMERICAN FOUNDRY GROUP

CERTIFICATION
AMERICAN FOUNDRY GROUP

Investment Division
14602 South Grant Bixby, OK 74008, U.S.A.
(918) 366-4401 - Fax (918)366-4802

Cast Date: 4/3/2019 **Material Specification:** CD-2-ASTM-A597 1987

Heat Number: 9D118 **Customer Address:**

Customer Name: MACHINING

Purchase Order: 3754-1-9

Part Number: W LONG KNIFE CD2

Heat Code: 9D118 **Serial Number:**

Chemical Analysis (%)

Element	C	Mn	Si	Cr	Ni	Mo	P	S	V	Cu	W	AS
Spec. Min	1.40			11.00		0.70						
Spec. Max	1.60	1.00	1.50	13.00		1.20	0.03	0.03				
Actual	1.5	.75	1.05	11.94		.90	.02	0.010	.6			
Element	**Fe**	**Cb/Nb**	**Co**	**Sn**	**Sb**	**Zn**	**Al**	**Pb**	**Ti**	**Mg**	**N**	**Zr**
Spec. Min												
Spec. Max												
Actual			.6									

C E: MAX ACT **Ferrite:** MIN MAX ACT **PREN:** MIN MAX ACT

Physical Properties **Residuals: MAX:** **ACT:**

(2" (50mm) Gauge Length per ASTM A370)

Ksi | MPa Ksi | MPa

Tensile Min: **Yield Min:** **Elong Min:** **Hardness:** **HBW Min:** **RC Min:**

Tensile Max: **Yield Max:** **Elong Act:** **HBW Max:** **RC Max:**

Tensile Act: **Yield Act:** **ROA Min:** **HBW Act:** **RC Act:**

ROA Act:

Yield / Tensile Min: **Yield / Tensile Act:**

Charpy:(ft-lbs) **Temperature:** F **Specification:** **Single:** **Avg of Three:**

Test 1: **Test 2:** **Test 3:** **Act. Avg:** **Min Lat Exp:**

Charpy: (J) **Temperature:** C **Specification:** **Single:** **Avg of Three:**

Test 1: **Test 2:** **Test 3:** **Act. Avg:** **Act Lat Exp:**

Special Notes:

Certification By: Vinton Goff / QC Manager **Date:** 4/3/2019

We certify that the casting(s) furnished on the subject order are in conformance with the material specification and/or purchase order requirements. The country of origin is the USA.
Castings are visually inspected and comply with ASTM A997.
This document complies with EN 10204 Inspection Certificate 3.1 FM-CP-LAB-002. Any actual results displayed as 0 indicates that all significant digits are 0's

Figure 3

This is the chemistry of D2 steel that was used for the axe

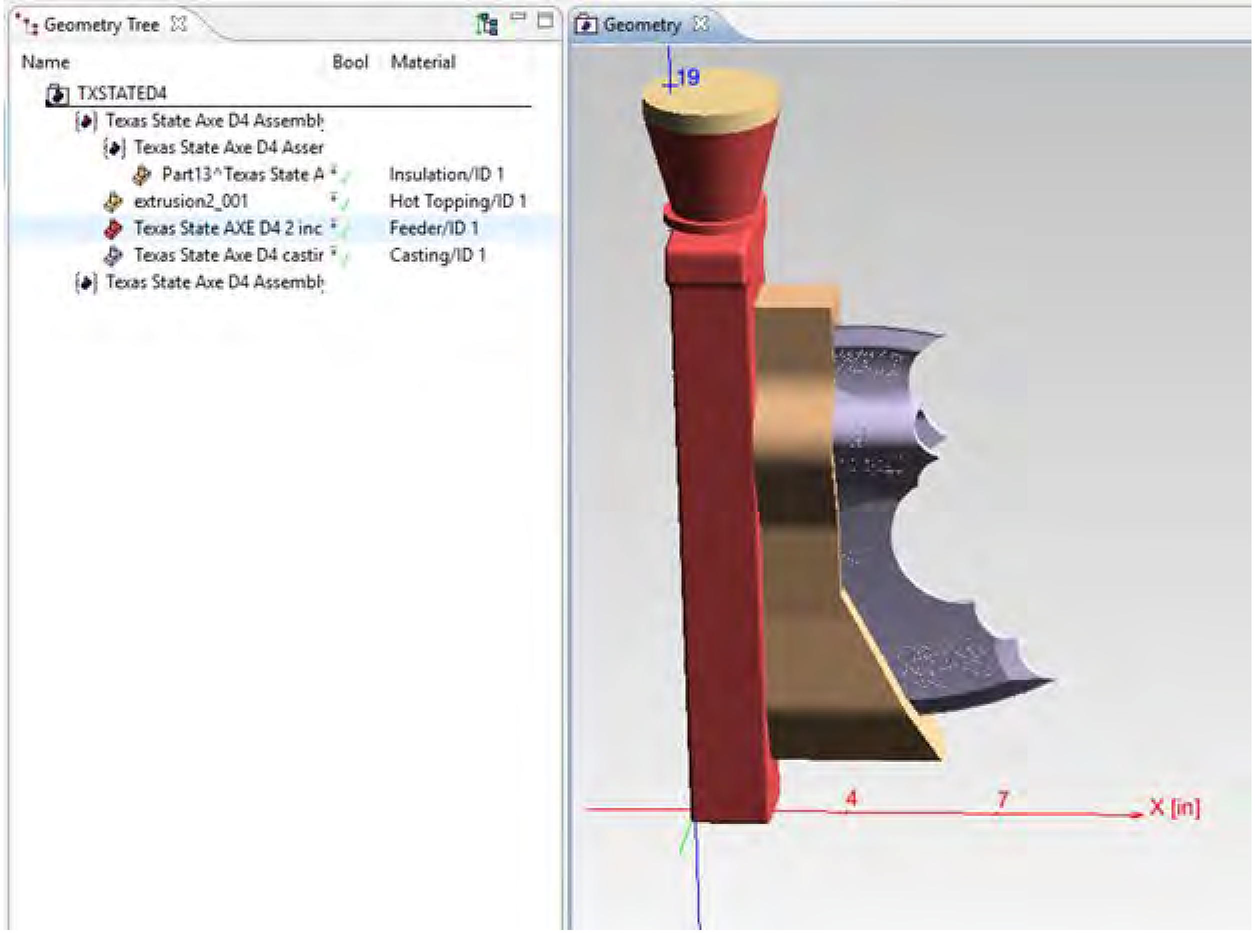

Figure 4

This is the single axe blade attached to the tree with the insulation and hot topping included.

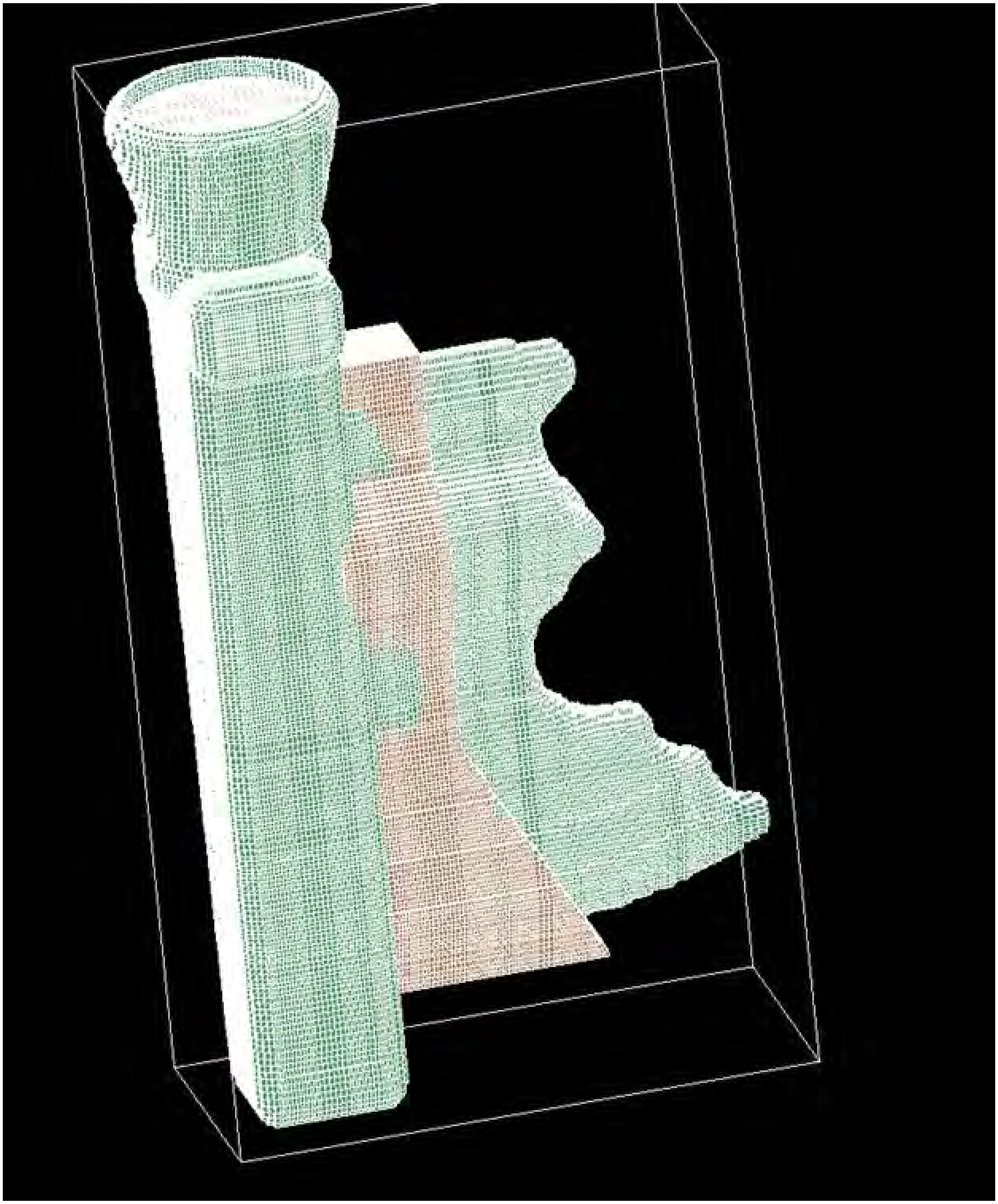

Figure 5

This is a screenshot for MagmaSoft of the mesh analysis used. The tree, insulation, and blade are included.

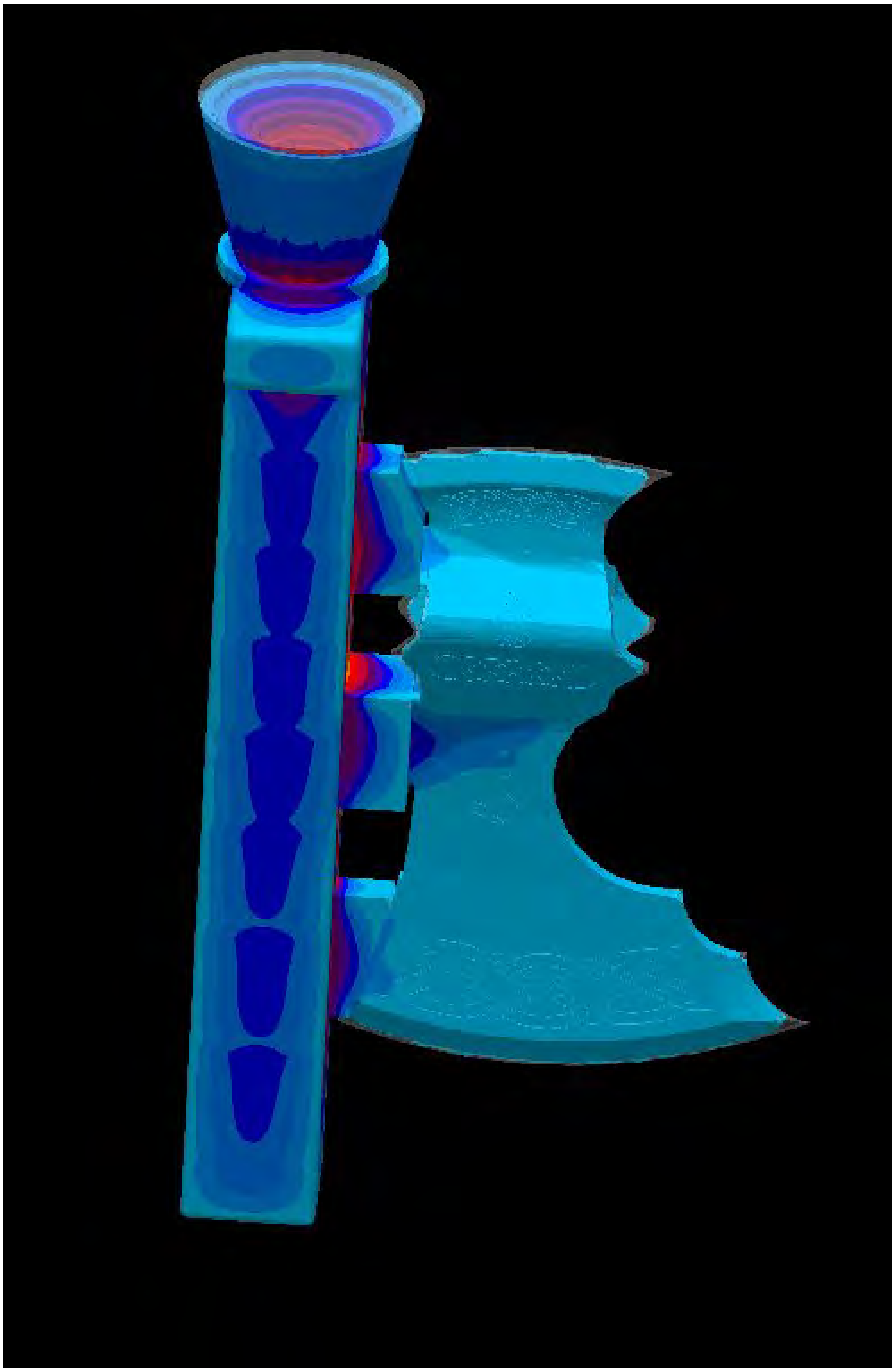

Figure 6.1

This series of photos show the solidification of the axe.

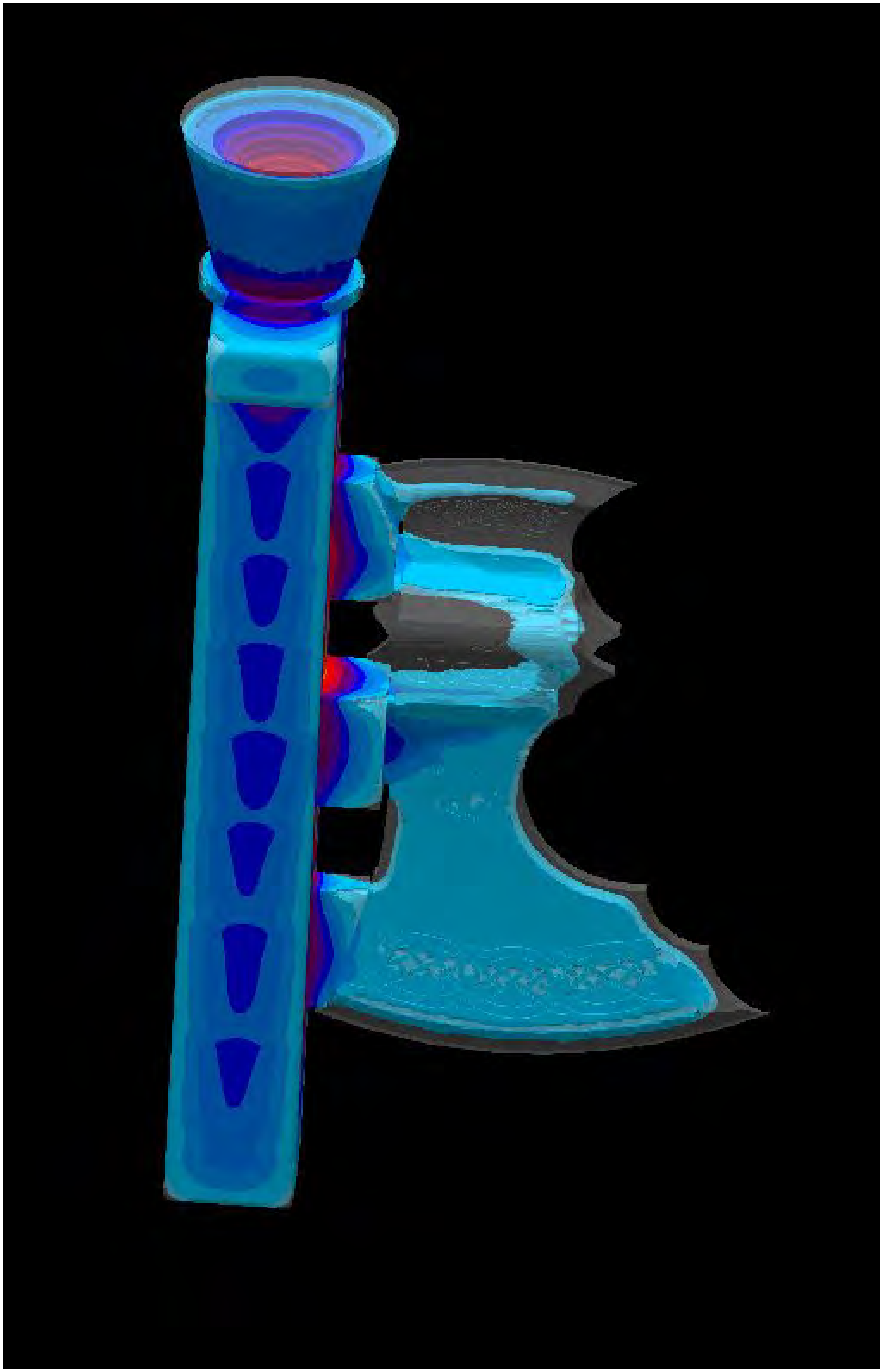

Figure 6.2

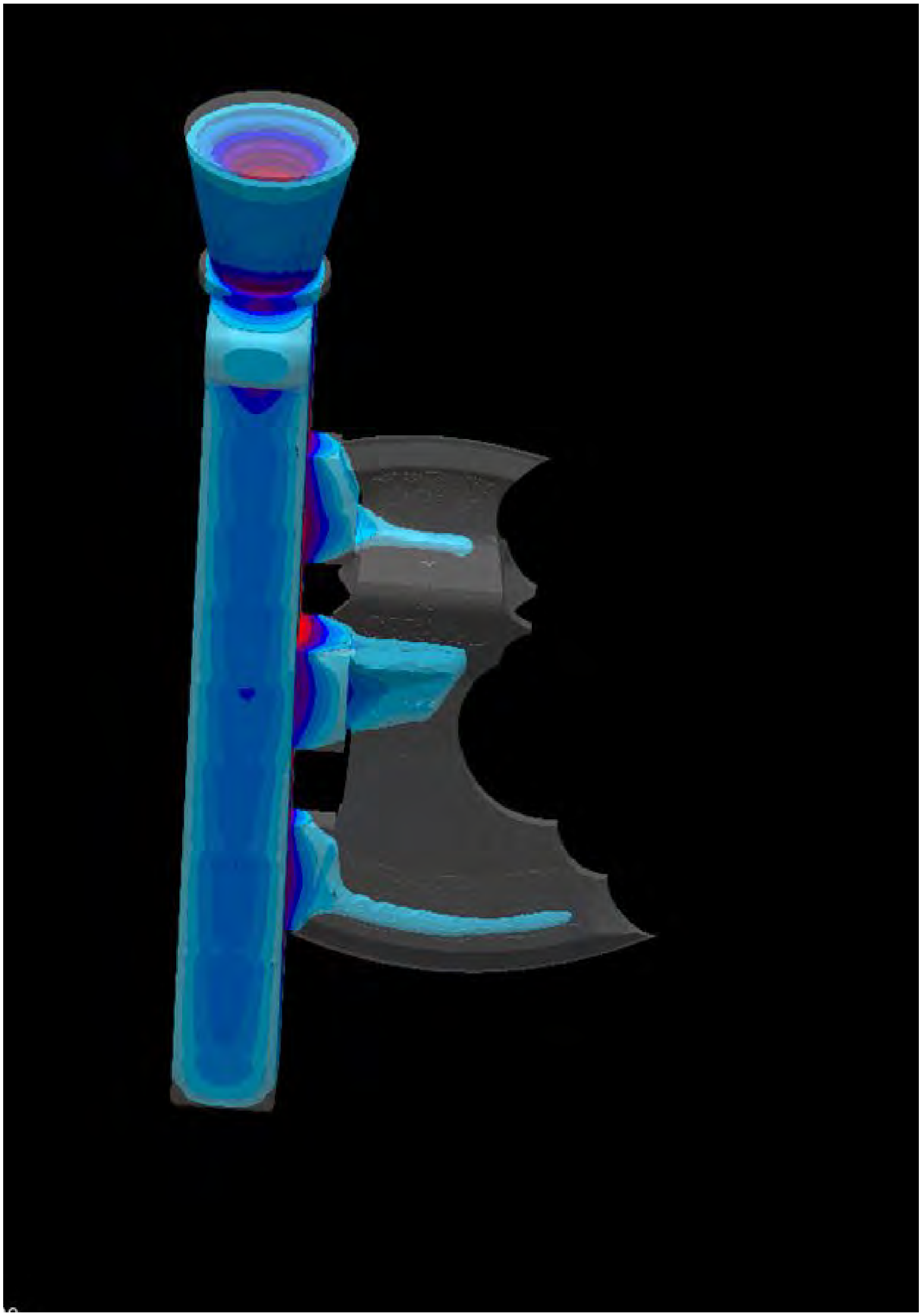

Figure 6.3

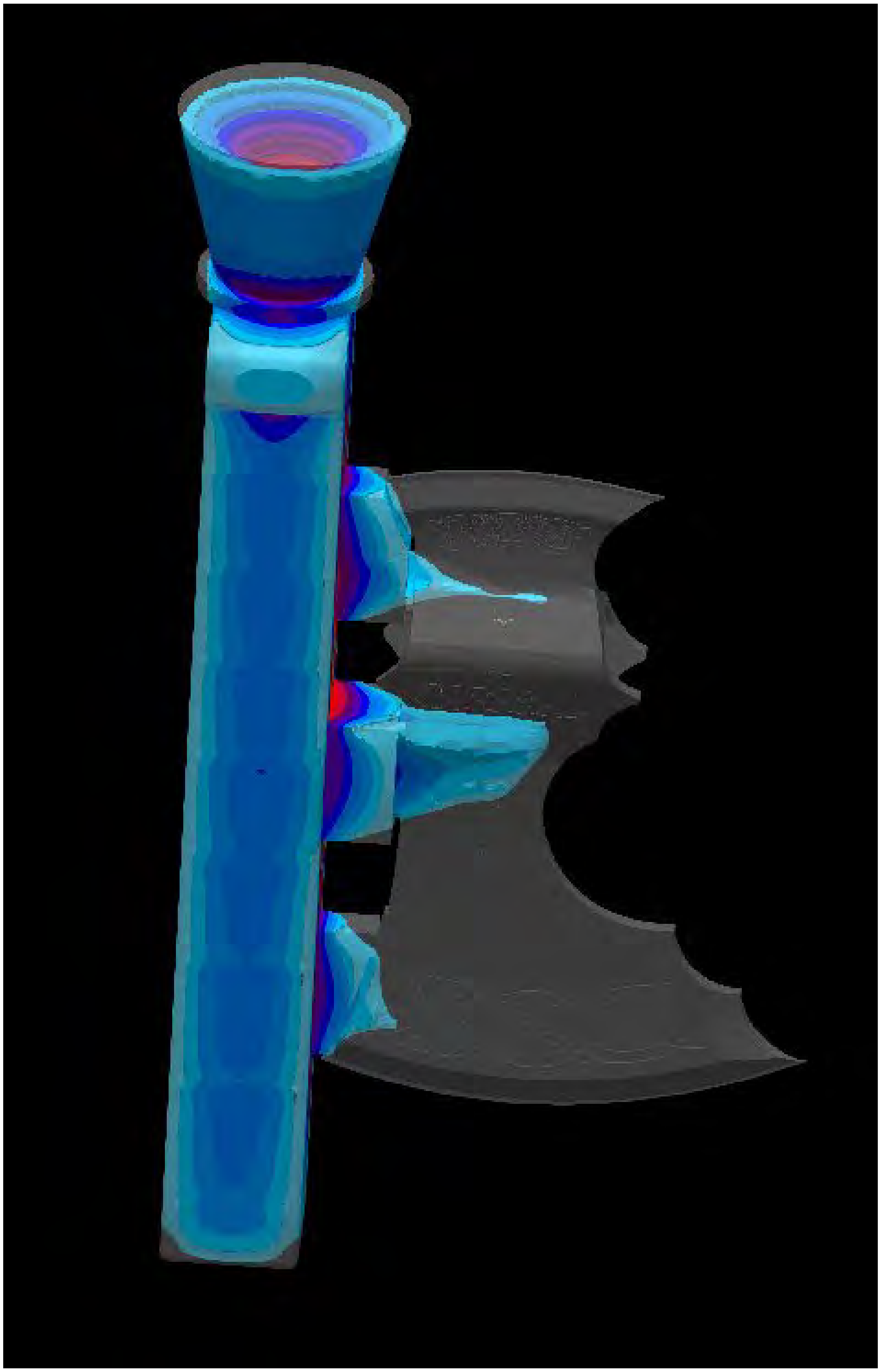

Figure 6.4

Figure 7

This is our 3D wax printed axe blade.

Figure 8

This is our axe with the dip shell coating.

Figure 9

This is out axe blade after being poured.

Figure 10

This is our completed Viking Axe.

Video

Video Fraction Liquid: https://youtu.be/-9ifQ0iqZRE

Video showing solidification through the liquid percentage in the axe.