



2019 SFSA Viking Axe Competition Technical Report

Penn State Behrend Student Team Members:

Jackson Craig, SO. Mechanical Engineering
Austin Hankey, SO. Mechanical Engineering
Elizabeth Gaughan, SR. Mechanical Engineering
Noah Esterline, SR. Industrial Engineering

Penn State Behrend Faculty Adviser:

Dr. Paul C. Lynch, Assistant Professor of Industrial Engineering

Penn State Behrend Foundry Industry Partners:

Urick Ductile Solutions, Erie, PA
PRL Industries, Inc., Cornwall, PA

Table of Contents

Title Page.....	1
Table of Contents.....	2
1. Introduction/ Background and Rationale Behind the Design.....	3
2. CAD Design.....	4
3. Simulation Modeling for Process and Performance.....	5-8
4. 3D Sand Printing.....	9
5. Steel Alloy and Chemistry.....	10-11
6. Melting, Pouring, and Shake Out.....	12
7. Heat Treatment Process to Develop Axe Head Properties.....	13
8. Images and Videos of the Production Process.....	14

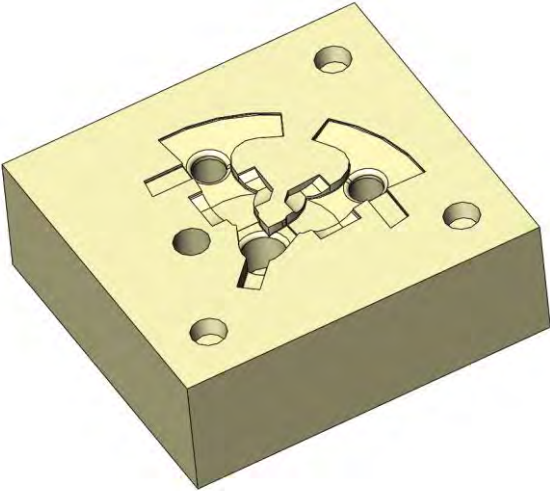
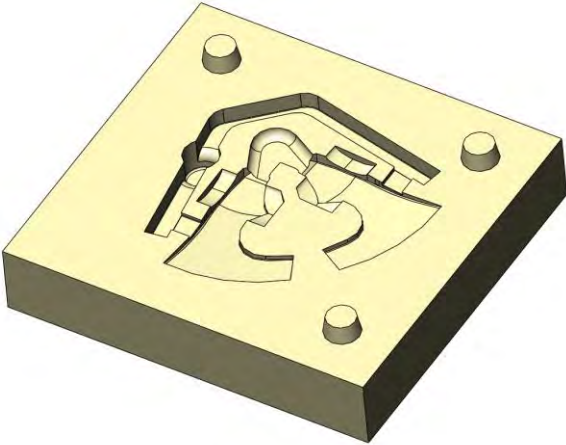
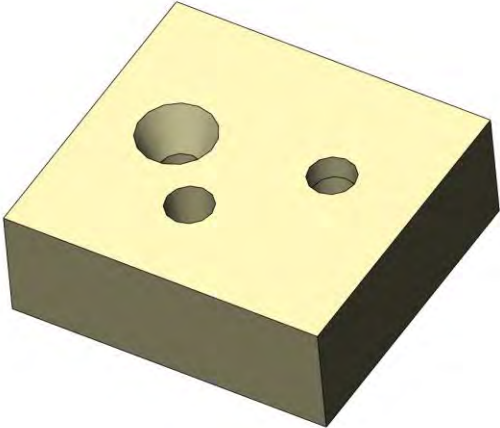
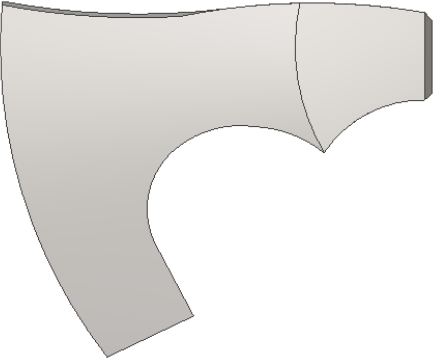
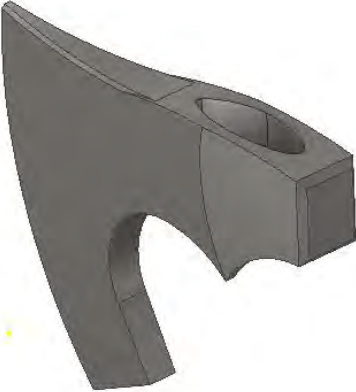
1. Introduction/ Background and Rationale Behind the Design

The axe that was designed and produced is modeled after both the “Wheeler III” axe (generically called a bearded axe) design used from roughly 600 AD to 850 AD and an American forest axe. As most Vikings were farmers, more often than not the weapons they utilized were the tools they used in the field. The same dual purpose can be seen in the axe designed for this project. The “Wheeler III” style was chosen because of its distinct association to Vikings as well as its beneficial design both on the battle field and on the farm. The long “beard” or blade/bit of the axe allows for both material and energy to be conserved. The larger blade/bit allows for more material to be engaged by the edge of the blade while not utilizing the same amount of material if the axe was solid. With the overall mass being reduced from this distinct bearded design, the Viking foot soldier would expend less energy per swing and tire less when it mattered most. Useful material was scarce during the age of the Viking, leading to lean manufacturing techniques being used. Most authentic Viking axes were constructed from pattern welded steel which was forge welded into a solid billet and drawn out into a small thin blade. Thin parts don’t typically lend themselves easy to be cast. Thus, in spirit of the competition, the overall size was increased from historical Viking axes to a larger more modern sized axe akin to an American Forest axe.

The edge geometry was selected to mimic that of axes produced today which have a convex edge. With a convex edge the maximum amount of material is behind the blade edge providing strength and rigidity against the immense forces applied to the bit. An added benefit of the edge profile is that while cutting, the material being cut is directed away from the blade of the axe, meaning that less friction will be produced as less material will be in contact with the cutting surface, making a cleaner cut with less energy expended. The axe edge was ground on a slack belt sander, starting at a rough 80 grit and working down to a finer 220 grit and ultimately a sanding belt to hone the edge. The axe was then attached to a hickory handle and a wedge driven into the top to secure it in place.

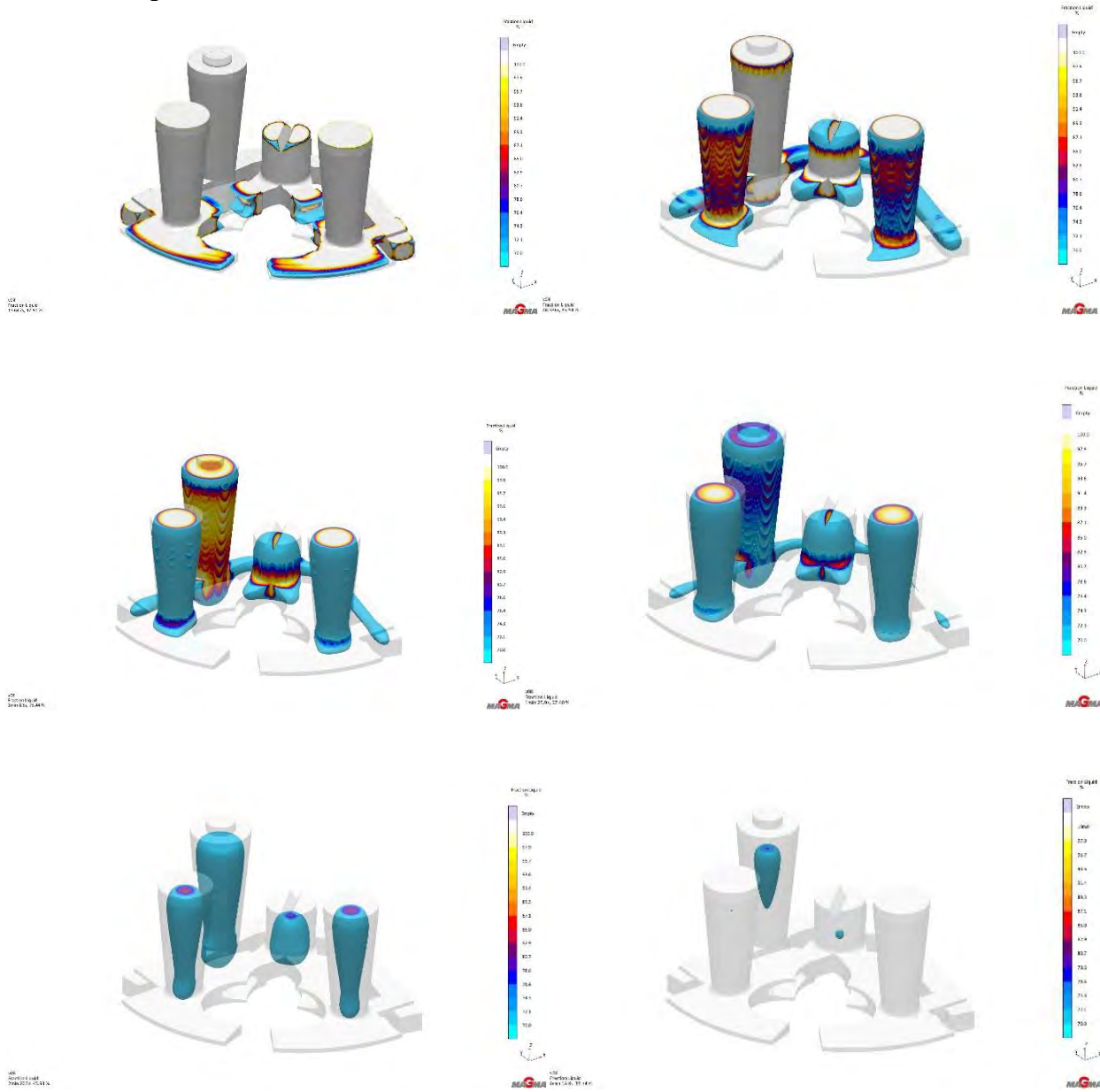
The alloy chosen for this axe is 5160 steel. The molds for the axe were 3D binder jet sand printed, a cutting-edge technology. The steel was then melted and poured and allowed to solidify in the sand mold. After solidification, the axes were heated to 1,700 degrees Fahrenheit and allowed to air cool (normalization). This alloy was chosen as the properties of the alloy allow for a near perfect axe head (given the proper heat treatment cycle). To attain the best combination of a hard edge and softer more shock absorptive (i.e. tougher) back or “butt” of the axe a differential heat treat was performed on the axe. The very edge of the axe blade was heated to 1,550 degrees Fahrenheit (Curry temperature, where the steel is no longer magnetic) while allowing for the remainder of the axe to stay relatively cool. The blade was then quenched directly in water (oil did not produce a hardened edge), hardening the blade. Once hardened, the edge of the axe will be very hard but too brittle to use as it will chip. To combat this, the axe was then heated to 400 degrees Fahrenheit to temper (Straw/Wheat yellow in color).

2. CAD Design



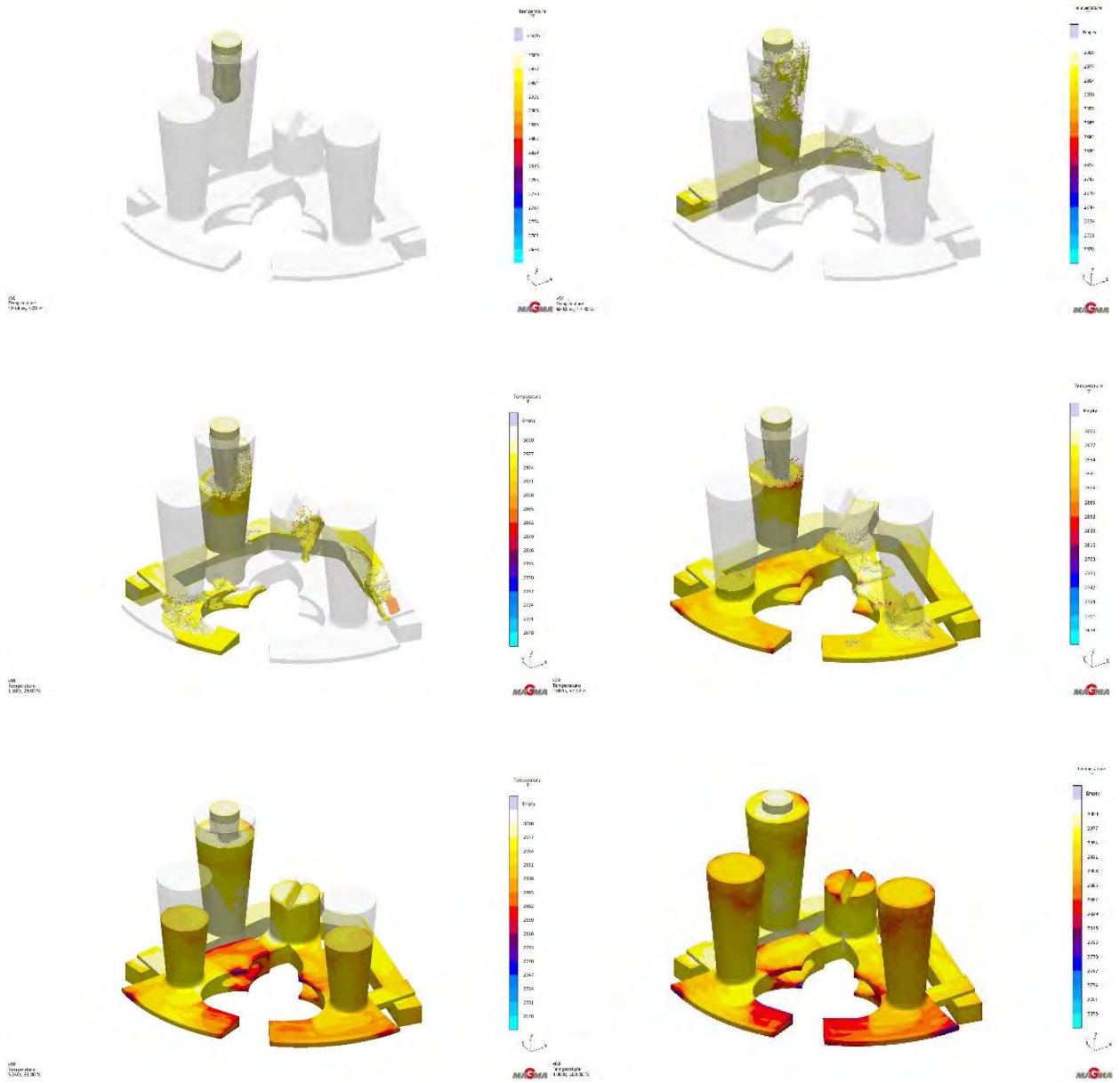
3. Simulation Modeling for Process and Performance

Fraction Liquid



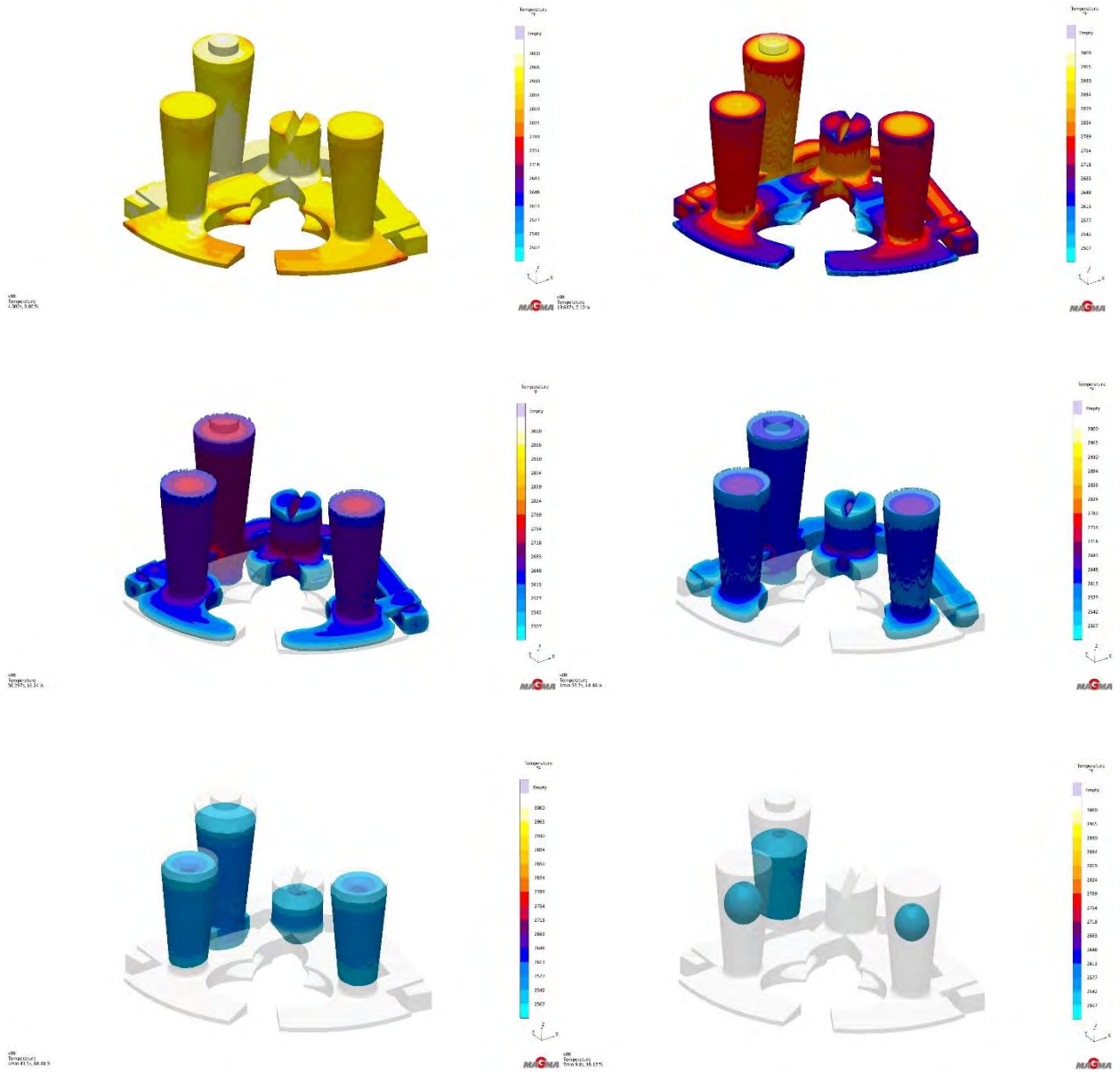
Fraction_Liquid.avi

Temperature Initial Flow



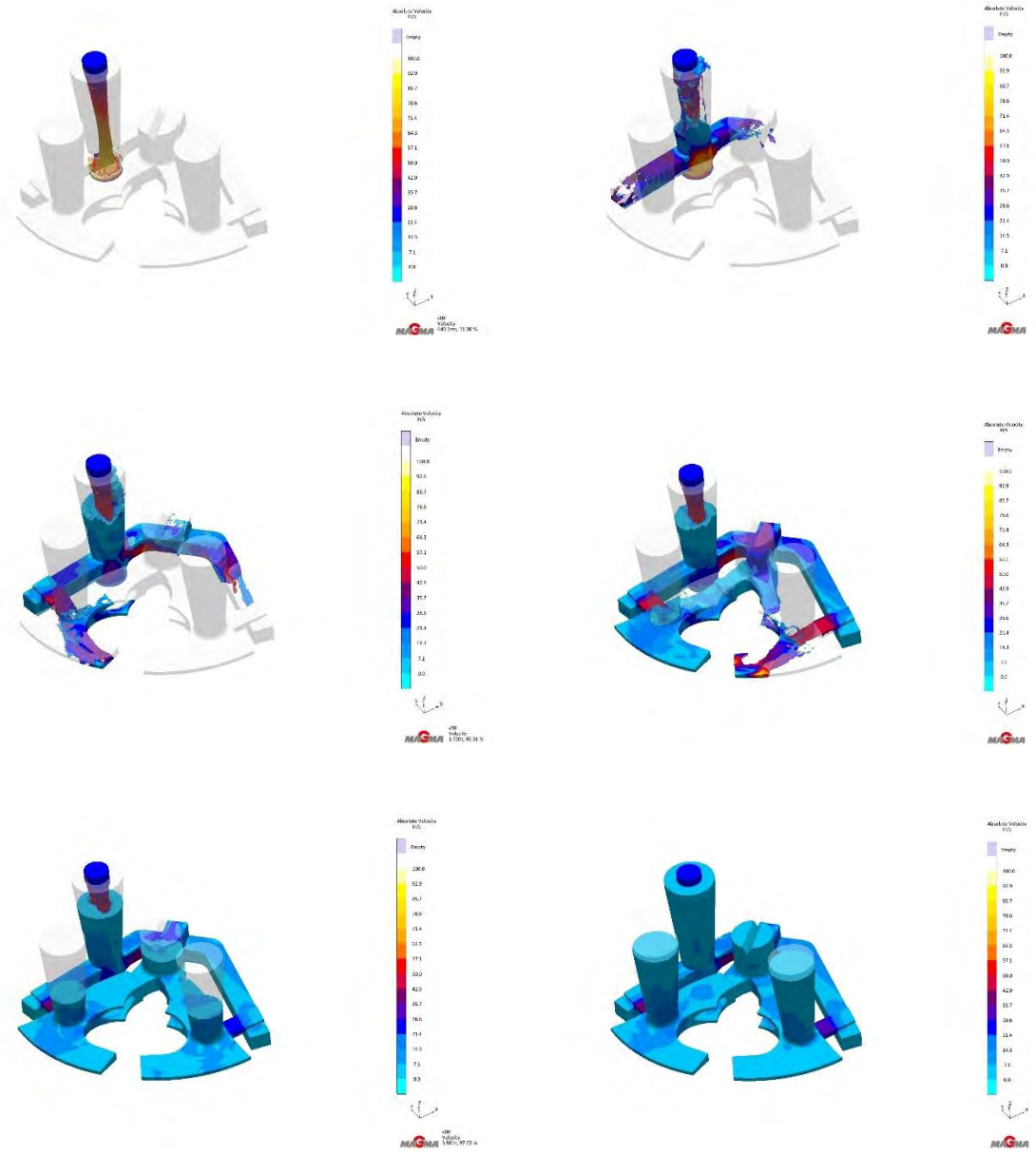
Temperature_Initial-Liquidus.avi

Temperature Solidification



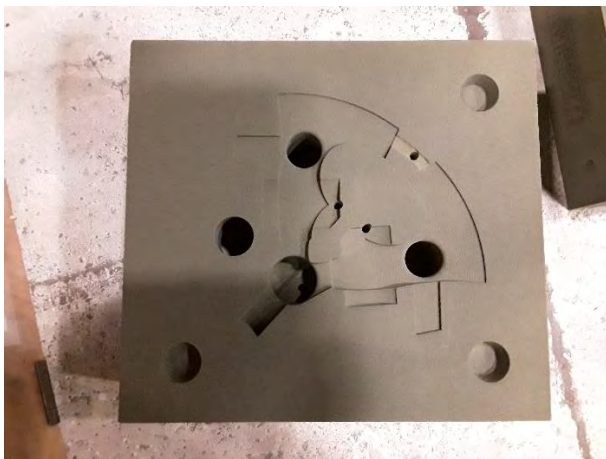
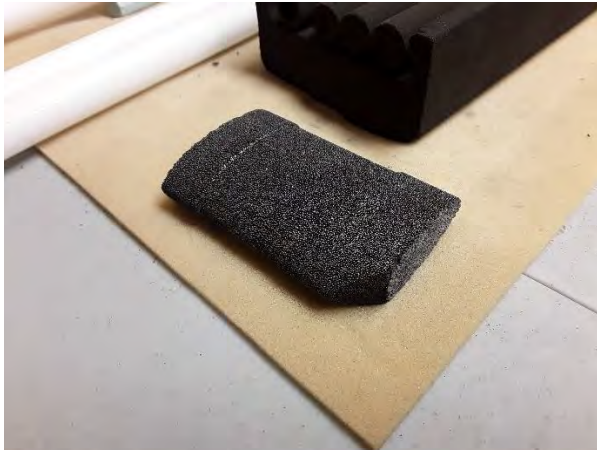
Temperature_Solidification_3000-2507.avi

Velocity



Velocity.avi

4. 3D Sand Printing



Mold Printing Partner: Hoosier Pattern, Inc.

Sand: Silica

Binder: Furan Resin

5. Steel Alloy and Chemistry

Alloy Steel 5160

Fe	Bal
Mn	0.75 – 1.0%
Cr	0.7 – 0.9%
C	0.56 – 0.64% (Stay towards lower end)
P	≤ 0.035%
Si	0.15 – 0.3% (Stay towards upper end)
S	≤ 0.04%

5160, 5160H

Chemical Composition. **5160.** AISI and UNS: Nominal. 0.56 to 0.64 C, 0.75 to 1.00 Mn, 0.035 P max, 0.040 S max, 0.15 to 0.30 Si, 0.70 to 0.90 Cr. **5160H.** AISI: Nominal. 0.55 to 0.65 C, 0.65 to 1.00 Mn, 0.035 P max, 0.040 S max, 0.15 to 0.30 Si, 0.60 to 1.00 Cr. **UNS:** 0.55 to 0.65 C, 0.65 to 1.10 Mn, 0.035 P max, 0.040 S max, 0.15 to 0.30 Si, 0.60 to 1.00 Cr

Similar Steels (U. S. and/or Foreign). **5160.** UNS G51600; ASTM A322, A331, A505, A519; SAE J404, J412, J770. **5160H.** UNS H51600; ASTM A304; SAE J407

Characteristics. Definitely considered a high-carbon alloy steel. As-quenched hardness of 58 to 63 HRC is considered normal. Sometimes values higher than this range are obtained, depending on the precise carbon content. Hardenability is slightly higher than that of 5155H. Used for a variety of spring applications, notably flat springs. Often uses austempering as a method of heat treating

Forging. Heat to 2200 °F (1205 °C) maximum, and do not forge after forging stock has dropped below approximately 1600 °F (870 °C)

Recommended Heat Treating Practice

Normalizing. Heat to 1600 °F (870 °C) and cool in air

Annealing. For a predominately pearlitic structure, heat to 1525 °F (830 °C), then cool rapidly to 1300 °F (705 °C), then cool to 1200 °F (650 °C) at a rate not exceeding 20 °F (11 °C) per hour; or heat to 1525 °F (830 °C), cool rapidly to 1250 °F (675 °C), and hold for 6 hr.

For a predominately spheroidized structure, heat to 1380 °F (750 °C), cool rapidly to 1300 °F (705 °C), then cool to 1200 °F (650 °C) at a rate not exceeding 10 °F (6 °C) per hour; or heat to 1380 °F (750 °C), cool rapidly to 1250 °F (675 °C), and hold for 10 hr

Hardening. Austenitize at 1525 °F (830 °C) and quench in oil

Tempering. After quenching, reheat to the temperature required to provide the desired hardness

Austempering. Austenitize at 1550 °F (845 °C), quench in molten salt at 600 °F (315 °C), and hold for 1 hr. Parts are cooled in air from 600 °F (315 °C) and need no tempering.

[1] Metals Handbook, 9th Edition, Volume 1, American Society for Metals, 1978.



PRL METALLURGICAL LABORATORY
 PO BOX 1170
 307 N. NINTH AVENUE
 LEBANON, PA 17046
 TELEPHONE: (717) 270-1888 FAX: (717) 270-2868

MATERIAL TEST REPORT

CUSTOMER: REGAL CAST, INC.

MATERIAL GRADE(S): 5160 Alloy Steel


CHEMICAL ANALYSIS (PERCENT)

HEAT NO.	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	V	Al	Fe	Sn	N	Ferrite
1999	.470	.750	.360	.007	.011	.780	.022	.006	.041	.001	.053	97.60		.009	

WE CERTIFY THAT THESE RESULTS REPRESENT THE ACTUAL ATTRIBUTES OF THE MATERIAL TESTED.

ALL MATERIALS PROCURED UNDER THIS PURCHASE ORDER MEET THE REQUIREMENTS OF THE DODD-FRANK WALL STREET ACT. (CONFLICT MINERALS)

COMMENTS Chemistry determination done IAW PRL-Chemistry Rev.3

TEST PERFORMED BY  CHARLES A. GOSS, LAB. MANAGER DATE 3/21/19

Form#112 Rev.1

The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statute.

6. Melting, Pouring, and Shake Out



7. Heat Treatment Process to Develop Axe Head Properties



1.mp4

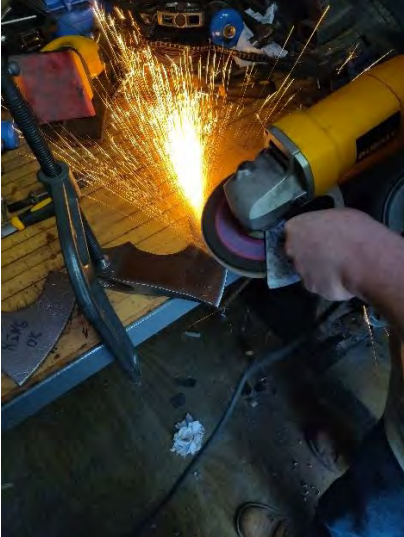


2.mp4



3.mp4

8. Images and Videos of the Production Process



4.mp4



blade.mp4



handle.mp4