Technical Report

Texas State University

Team 2

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We first want to recognize our incredibly helpful sponsor, American Foundry Group, for giving us this opportunity to compete.

Rationale behind the design

Our initial design discussion began with researching the distinctive design features and the history of a traditional Bowie Knife. We noted several key features of historical knives such as the Spanish notch that is symbolic of the Bowie knives' Spanish origin. We chose a spear point instead of the clip point to increase the structural integrity of the tip. The pommel was designed wide and flat instead of rounded to incur structural integrity for use of hammering to the pommel. The S shaped guard was chosen because it offered a wider protection for the hand versus a coin shaped guard. The D guard offered better protection for the hand but would have been more difficult to cast and process. We chose a 9.5-inch blade because anything longer could warp or cold-shut as the metal solidified. Finally, a Bobcat sigil was added to the pommel as a design touch to represent our school.

Alloy and processing to get properties

Our thought process for the alloy started in stainless steels as they are common tool steels for making knives. They are known for an overall balance of hardness, wear resistance, and corrosion resistance. The alloy 440C was our first choice and was commonly melted at our sponsor's foundry. In researching 440C we came across 154CM which has a very similar chemistry to 440C with a typical ratio of 4% Molybdenum. 154CM shares many of the same properties as 440C but with improved hardness, wear resistance, and corrosion resistance. This would put our casted knife at the higher end of the 440C hardness (58 to 62 HRC). Our sponsor was able to use available 440C and add Molybdenum to create our alloy.

Production processing used

In the processing phase, our knife model was prepped for the investment casting process. This began with 3D printing the model with the gates into a castable material. We had many different options for 3D printing including printing at our university lab in PLA or castable wax. Both options eventually fell through as our equipment was not large enough nor precise enough to make a quality print. Quality was important at this point as any defects would transfer to the metal in the cast. We ended up using a third-party 3D printing company called Voxeljet. This was a trusted company used often for casting purposes by our sponsor foundry. The model was printed precisely using PMMA with a Wax infiltration, a material that could be easily melted out of the mold.

When the printed model arrived, it was sent to be attached to the tree and runners provided by the foundry. The whole assembly was coated in a shell material used by our sponsor to create the mold. The mold was sent to an autoclave to evacuate all wax and PMMA material. We then did a 1500 degree burn out to remove any residual wax or PMMA from the mold cavity.

The shell was preheated to 1800 degrees before removing from the oven to pour the metal. During the pour we blew compressed air on the edge of the blade to help start solidification and to increase the cooling rate. Our goal by doing this was to create finer secondary dendrite arm spacing and directional solidification.

After the mold cooled, the shell was broken apart and removed from the metal. In the first cast inspection, there was some non-fill areas along the blade edge. A second casting was done with an increased shell pour temperature from 1800 degrees Celsius to 2000 degrees Celsius to ensure metal could flow throughout the blade. During the cleanup process, the gates were cut from the knife and excess metal was ground off. The knife was then sand blasted to clean the surface.

Description of the manufacturing

Our manufacturing process began by grinding and cleaning all surfaces of the knife. Our next step originally had been to heat treat the knife by tempering right under 800 degrees Celsius and then quenching with an oil and refrigerant, as recommended by Crucible Industries. However, due the circumstances and our lack of resources for heating and testing, we decided to keep knife as had been casted. We then focused on sanding the blade and sharpening the edge by following the designed angle of the blade. This process used different grain sizes of sanding belts working from coarse to fine grain. Unfortunately, we came along some areas of porosity along the blade that were deeper than expected and were not able to smooth them out without risk of the blade becoming too thin. We suspect this porosity was a defect formed in the casting and solidification phase. Our next step was placing the scales to form a handle. Wooden blocks were cut down to the length and thickness of the handle. After sanding the surface metal, a two-part epoxy of clear J-B

Weld was used to permanently attach the scales. The wooden scales were then sanded and smoothed down to form the shape of our designed handle. After the epoxy was able to set and cure, we did a final polishing of metal surface area using a rotary Dremel tool. We did another final sharpen on the blade using a knife sharpening block. The final touch was applying linseed oil over the wooden scales to protect and seal the wood for a polished finish.

Test results for the quality and properties

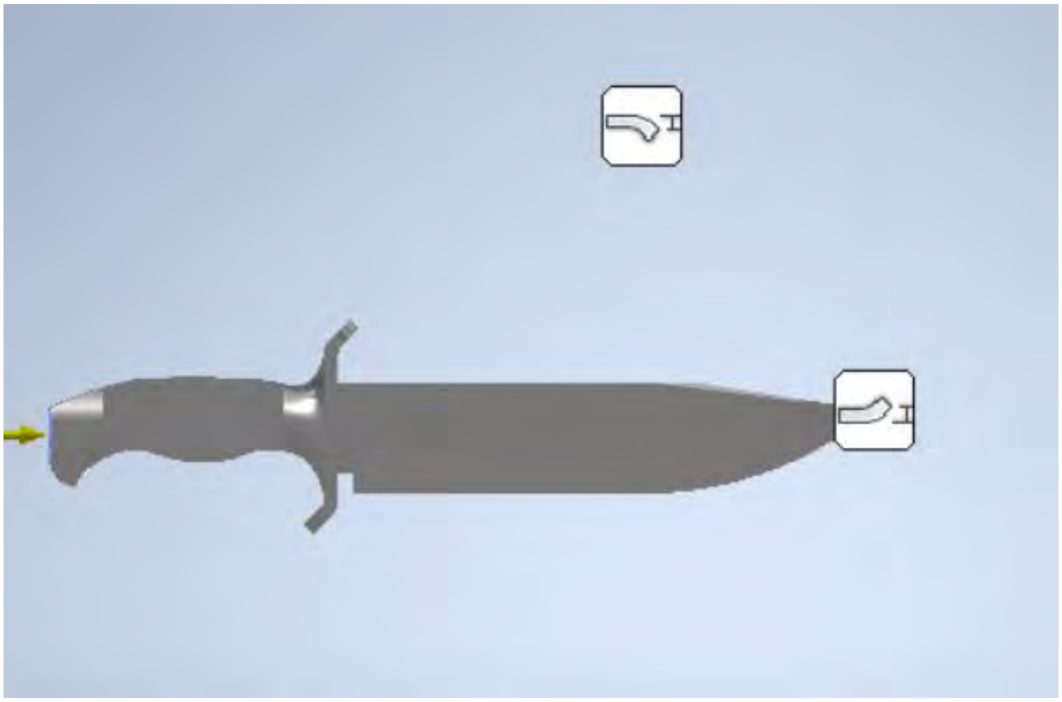
Unfortunately, due to the pandemic shutdowns, we were not able to use official testing equipment for hardness or strengths. We were able to test the knife similarly to the testing that would take place at the competition ceremony. We obtained our sponsors first cast of our knife, which had been defected, and used this in our testing process. After seeing the typical testing routines that take place on the show "Forged in Fire", we set up several test materials of which included carboard, deer antlers, and a tree stump. The knife was first tested on the cardboard for sharpness and smoothness of cut by stabbing and then slicing through the cardboard. The blade performed well without drag. We then used the knife in a chopping motion to observe the edge for any rolling or chips. The chopping was tested again on the tree stump. Both chopping tests resulted in zero rolling or chipping, proving that the blade had a particularly good hardness and strength. Finally, the knife blade tip was tested by touching the tip to the tree stump while the pommel was hit with a hammer. The tip held very strongly without a chip or fracture and travelled further into the stump. The pommel also withstood the hammer impact without any deformation, again showing the toughness and hardness of the alloy. The knife performed and exceeded our expectations as designed.

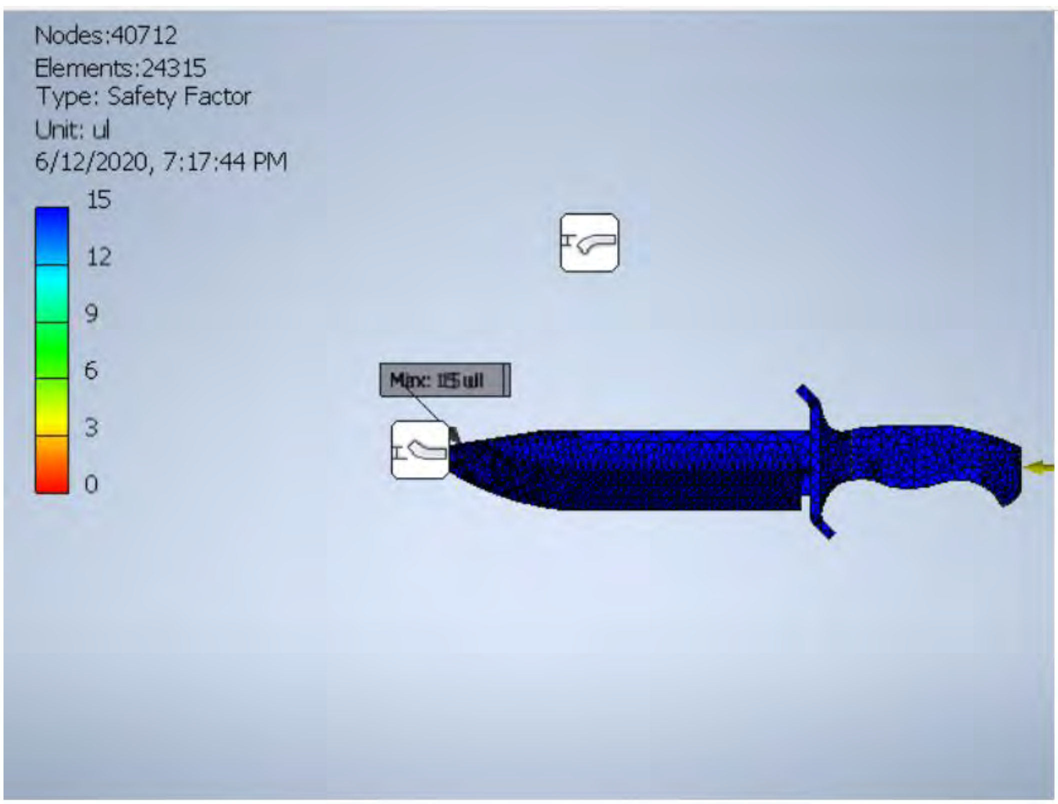
Modeling for process and performance

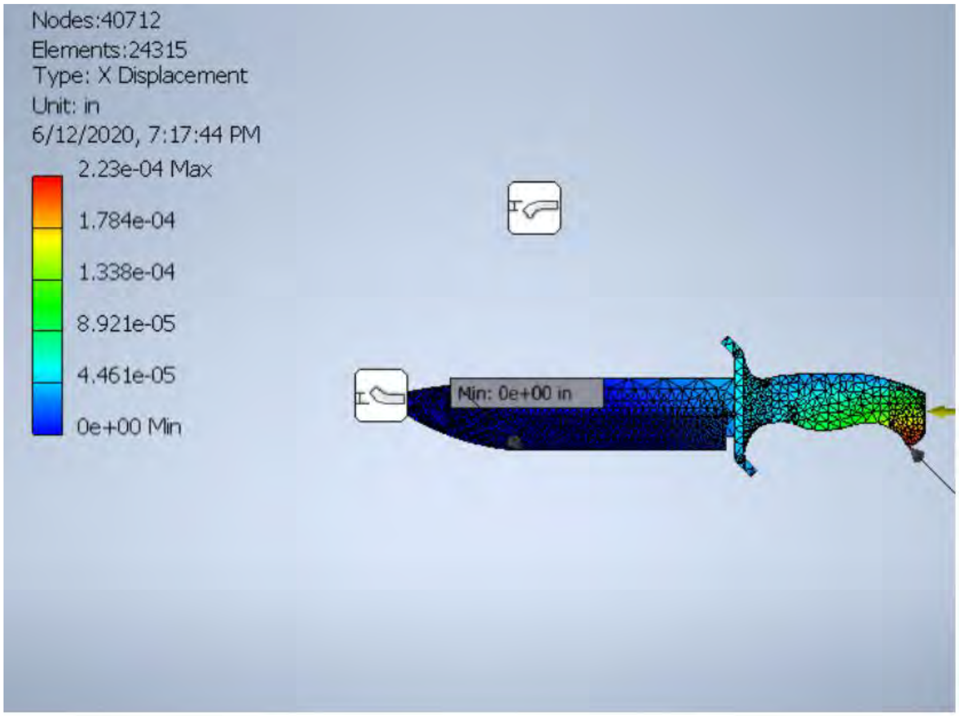
The knife model was created in Inventor as one whole part. We designed the knife model to include all features in the final cast without needing excessive extra forming or cutting. The blade edge was modeled with a passive blade angle and an edge of .003 inches to ensure ease of sharpening. We decided to keep the pommel attached to the tang in order to simplify the manufacturing and ensure the strength was not compromised. The model was used to pinpoint the center of mass as we tried to create a perfectly balanced handle to blade ratio.

Stress testing was done in the modeling phase of the knife to find increased stress build up and points of weakness. Our first test was a hammering simulation with a 100-psi force to the pommel while the tip was constrained. The second test was a chopping simulation in which a 100-psi force was applied to the cutting edge while the handle was constrained. Both simulations resulted in a high safety factor value and minimal displacement.

Hammering Autodesk simulation result. 100 psi force to the pommel. Blade tip and sides were constrained. Safety factor and displacements shown.



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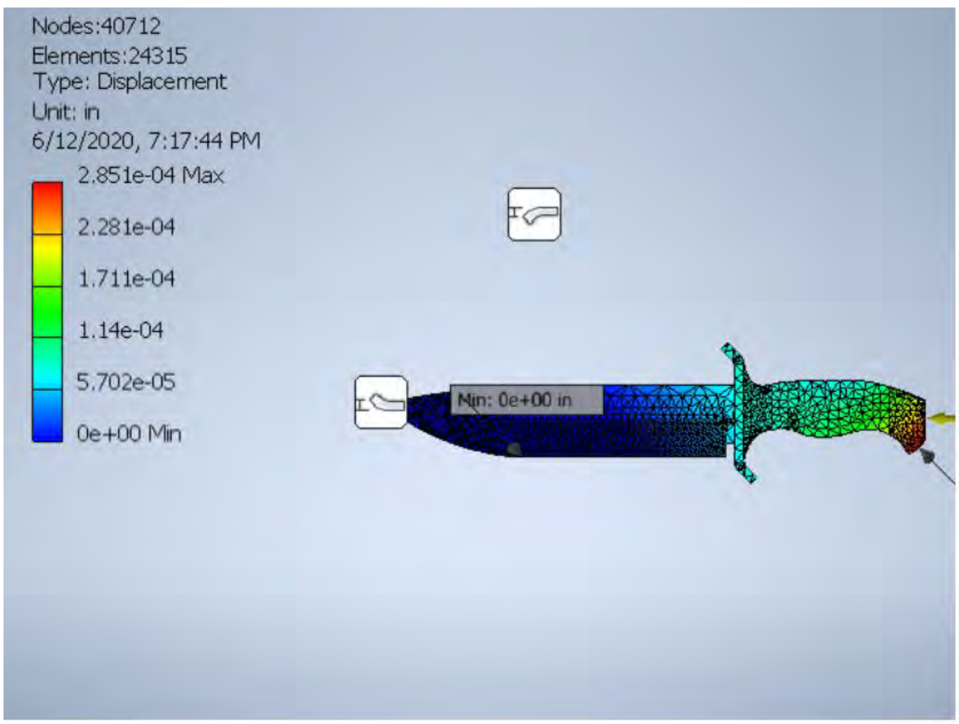
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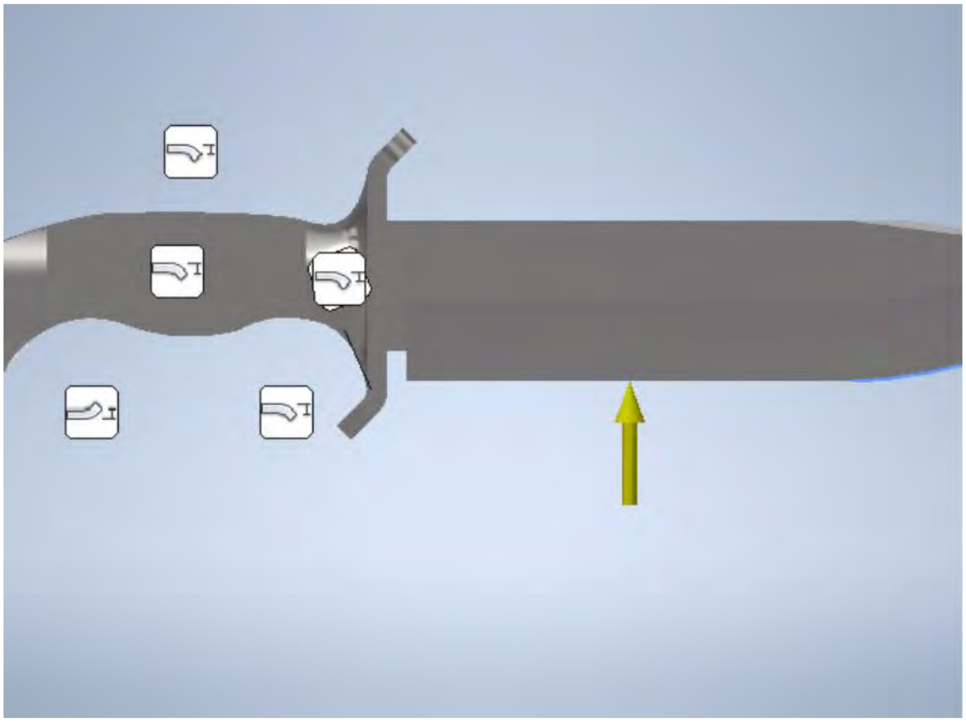
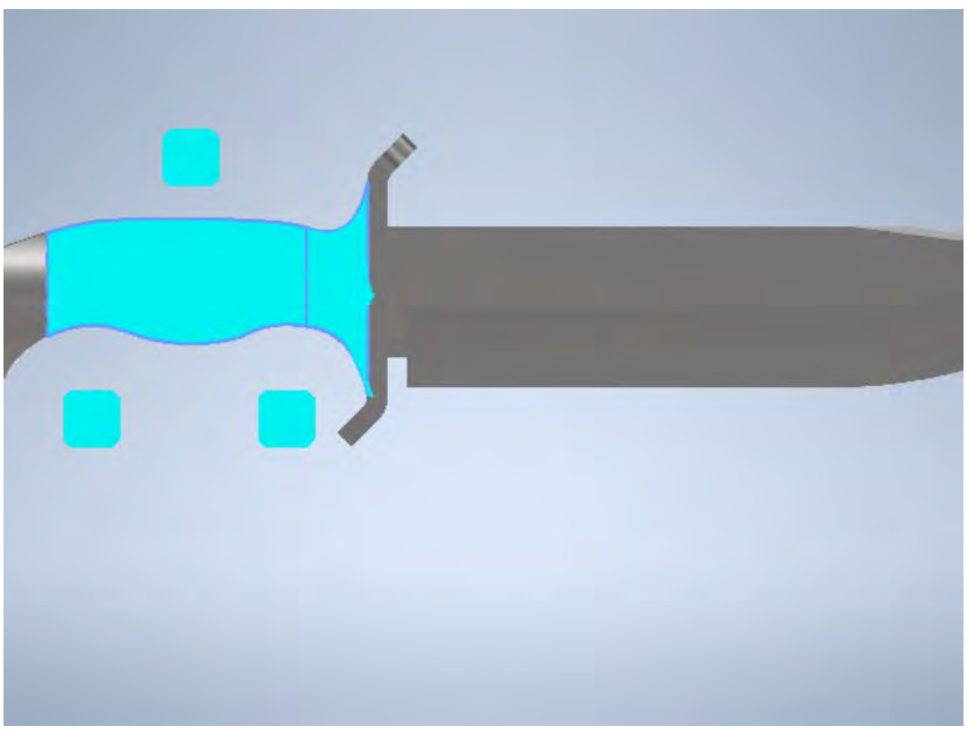
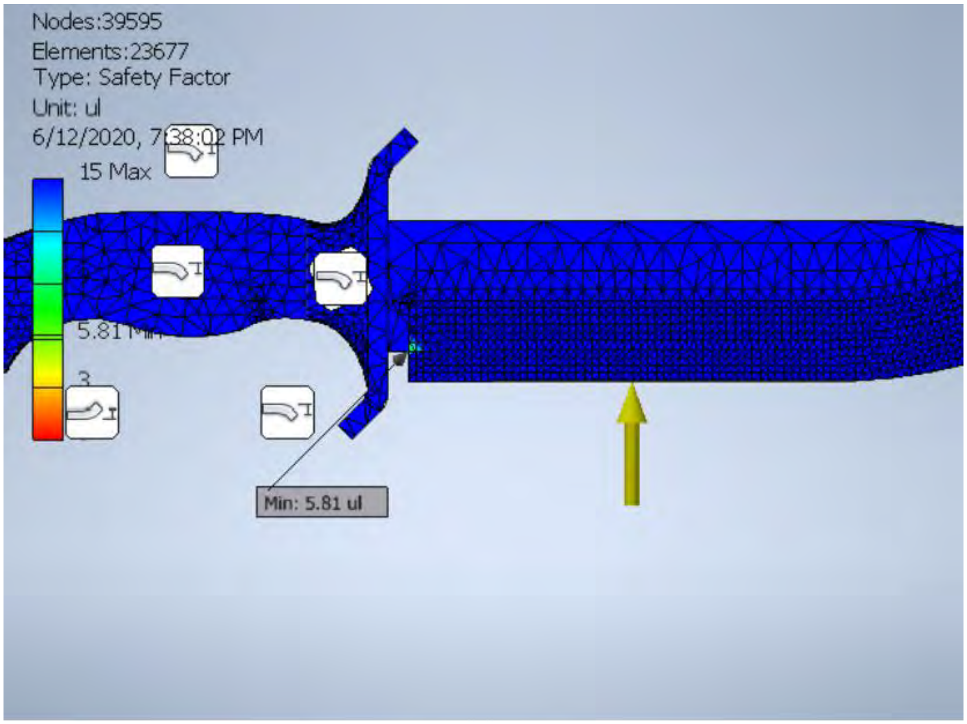
Chopping Autodesk simulation result. 100 psi forces to the cutting edge. Handle had constraints. Safety factor and displacements shown.



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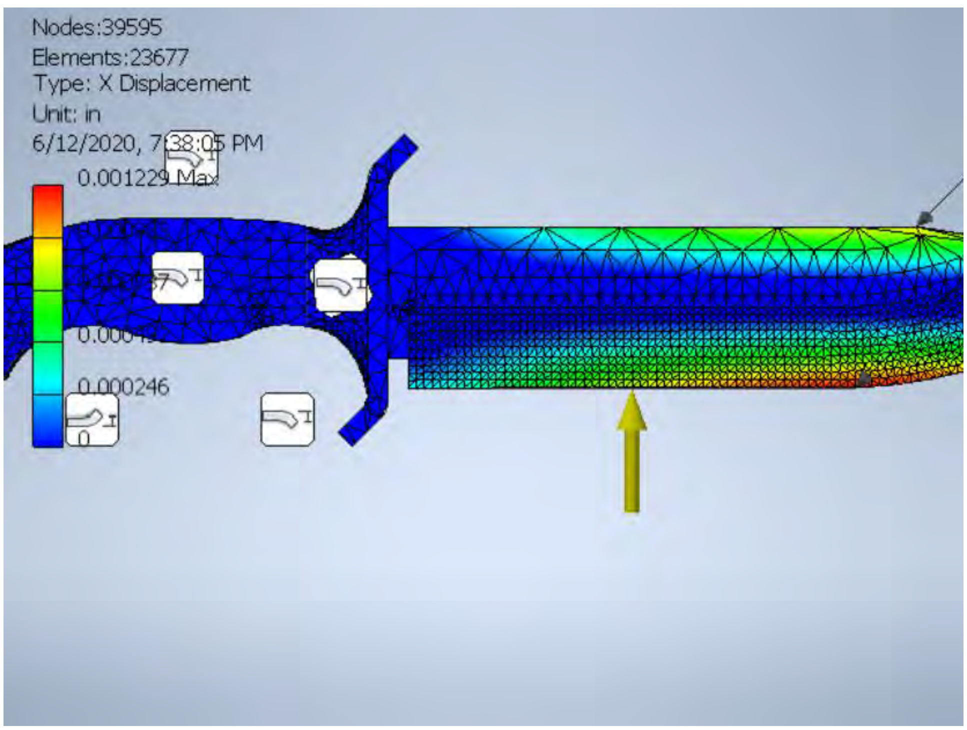
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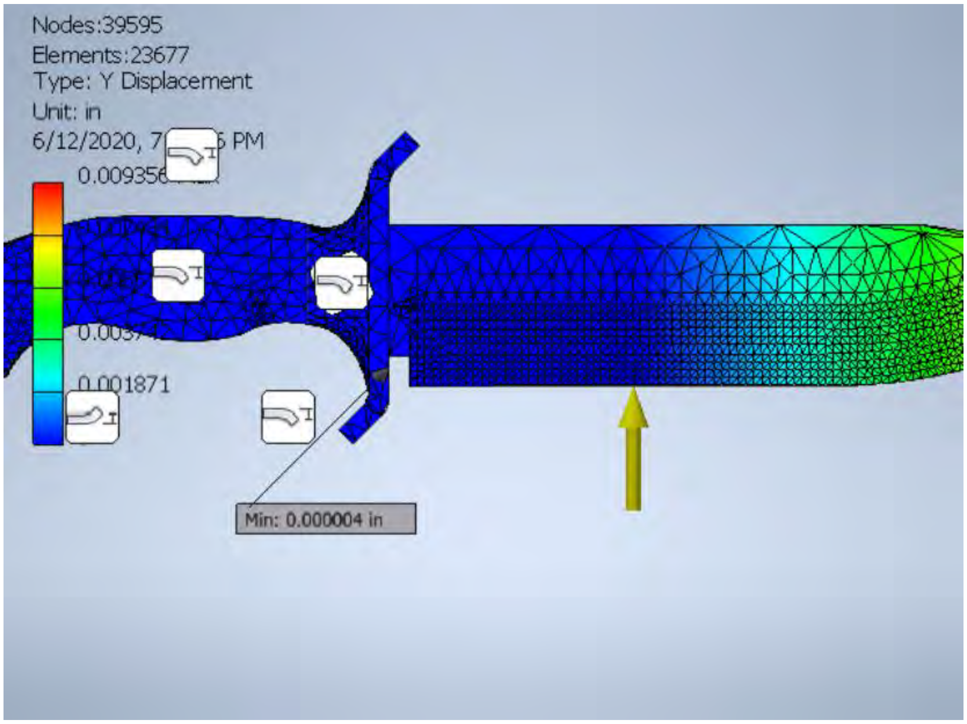
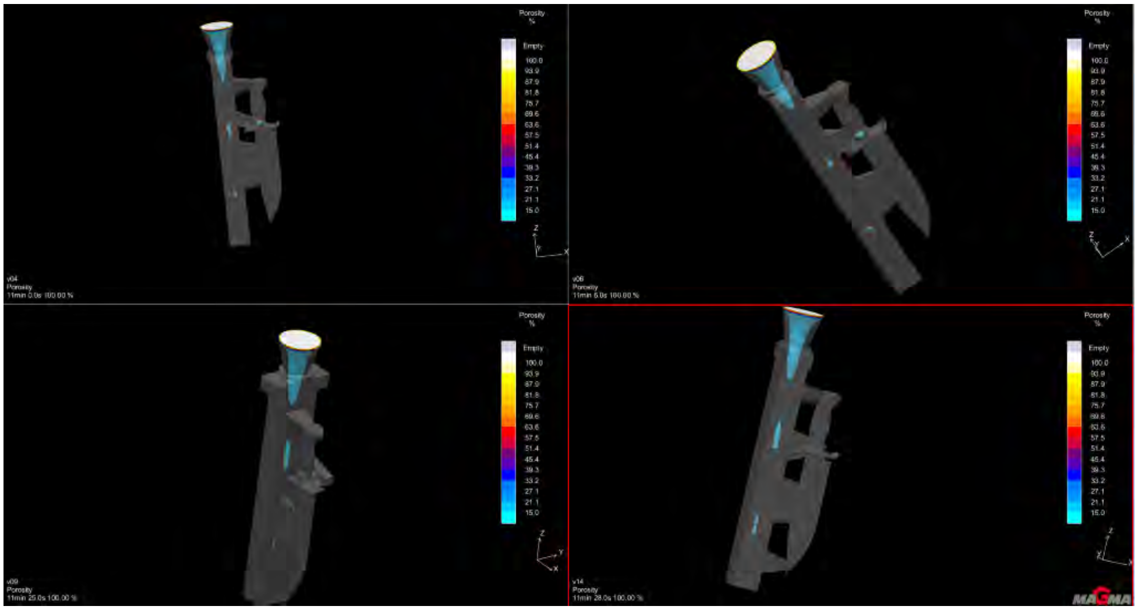
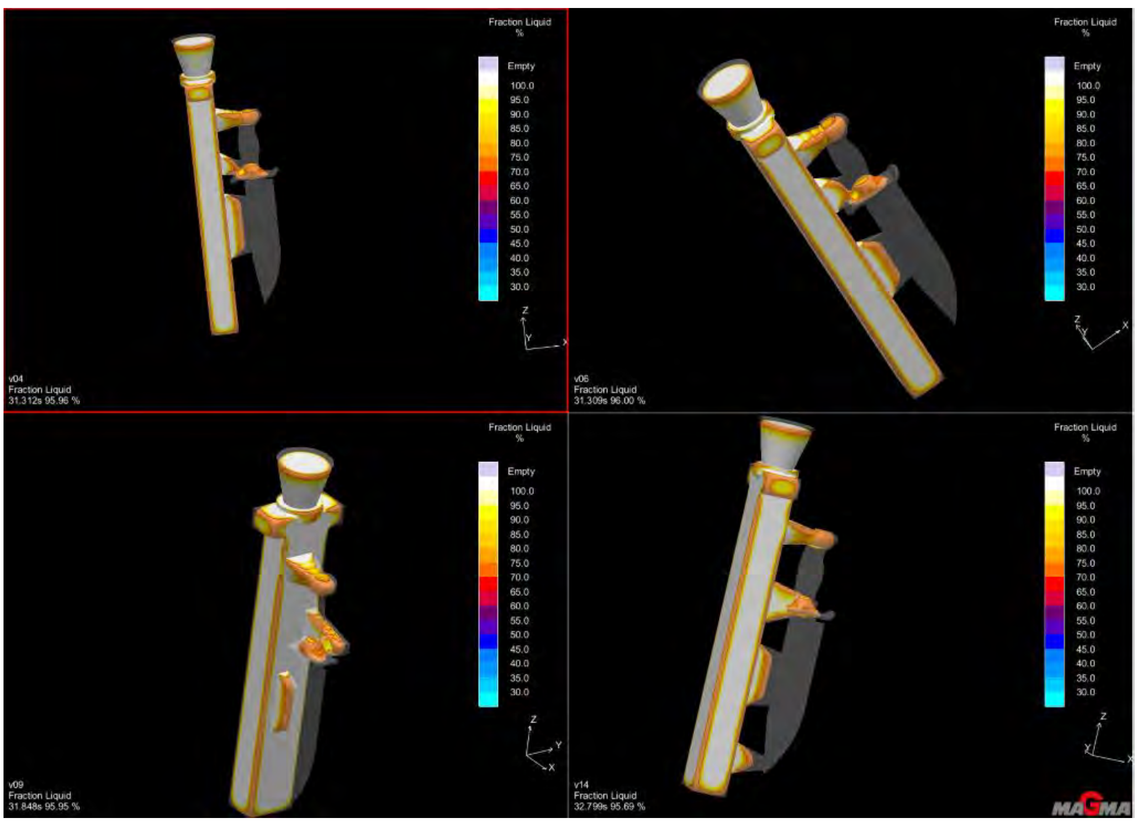


Using our sponsor’s Magmasoft software we were able to simulate the casting process. Our results gave us insight into the size and location of our runners to insure proper flow. The results also included possible areas of shrinkage. The images below show a few of our results. The top left image is the first simulation and shows shrinkage at the handle. In the top right image, the gate size was increase but the shrinkage was still there. The bottom left shows the gate was moved to side of handle. Finally, the bottom right shows an added gate to the tip of the blade to help keep the model straight when attaching the gates.





Finished Blade

Finished Guard

Finished Tang

Finished Knife