3D Printed Shovel Handle Report

Test Sample Design

The design of the shovel handle begins with a tensile testing platform that will enable us to find an optimal printing configuration for the printed handle. To begin, a tensile test using 3D printed "dog bones", shown and dimensioned in Figure 1 and Table 1 below, will be used as the control in testing different print infill orientations. The expectations with the different infill configurations are to try and reach optimal ultimate strength and strain under tensile loading.

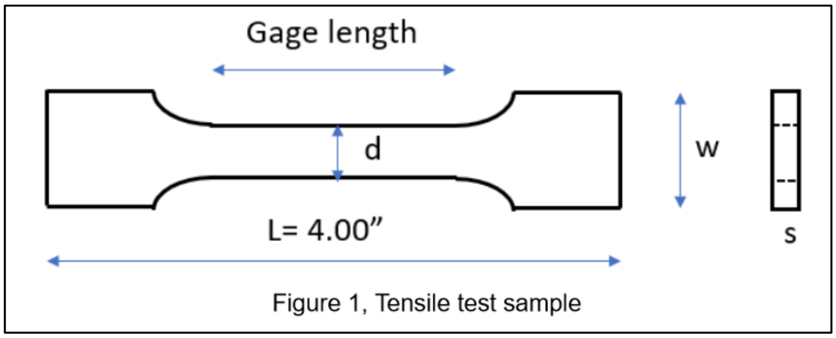


Figure 1: "Dog Bone" Tensile Test Configuration

Width (w)	1.000"
Gage Length	1.750"
Grip Section Height (s)	0.125"
Gage Cross-Section Width (d)	0.500"

Table 1: 3D Printed Dog Bone Configuration

For the infill configurations, six different approaches were selected for the infill in order to try and optimize the strength and ductility of the print, all of which can be seen in Figure 2 below. All 6 pieces maintained the original geometry mentioned above, with a 20% infill using PETG (polyethylene terephthalate) filament that was printed on a Creality Ender 3 V2 FDM (fused deposition modeling) printer. The printer was configured with a shell thickness of 0.8 mm with 4 top and bottom walls, and 2 wall lines; all of which are standard settings provided for this printer specifically. The PETG was selected due to its higher melting temperature and better ductility characteristics compared to the PLA and ABS filament stock that was on hand.

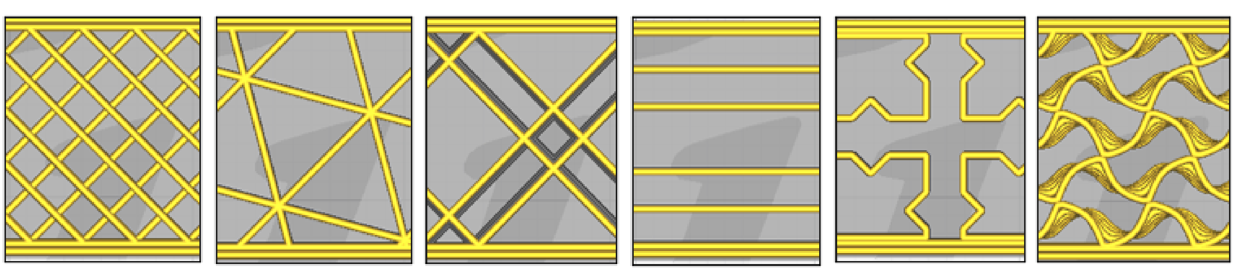


Figure 2: The 6 different infill patterns: lines, triangles, octet, concentric, cross, and gyroid

Tensile Testing & Interpretation

Tensile testing was conducted in a lab setting where the dog bone was clamped on the larger width ends while a continually rising tensile force was applied to the part. Data was logged showing the load and travel between the ends of the test piece over time. With this information, we were able to plot the stress applied to each part using the applied force divided by the gauge length area (d x s from Table 1) along with the accompanying strain by dividing the clamp travel by the original gauge length of 1.75 inches ($\Delta L/L$). The total combined results can be seen graphically for the 6 configurations in Figure 3 below. Each of the independent graphs can be found in Appendix A1.

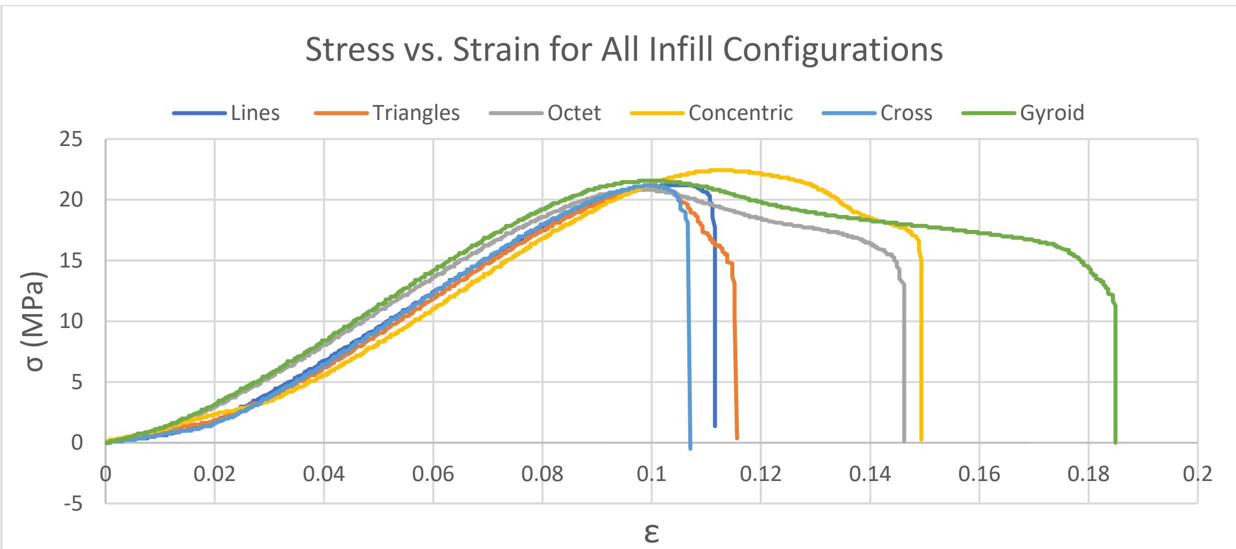


Figure 3: Stress vs. Strain plot for all 6 print configurations

Maximum ultimate stress and strain values for each configuration were found during the data processing and shown in Table 2 below. One thing that is quickly evident from the stress-strain graph is that all configurations have a similar young's modulus as their stress/strain ratio rises at roughly the same rate. However, past the yielding point they all tend to vary in terms of the stress and/or the ultimate strength. In Table 2, highlights point toward the largest values determined for each category, showing that the concentric and gyroid configurations performed relatively well in both domains.

Print Configuration	**Ultimate Tensile Strength (MPa)**	**% Elongation to Failure**
Lines	21.2	11.2
Triangles	21.0	11.6
Octet	20.8	14.6
Concentric	22.4	14.9
Cross	21.2	10.7
Gyroid	21.6	18.5

Table 2: 3D Printed Tensile Test Material Properties

We were able to compare our testing results with another team that used PLA instead of PETG, a 50% infill, and some of the same infill configurations that we used as well. Most of their prints produced ultimate strengths within the 15 – 32 MPa range, with the higher one being due to a print orientation that had a linear infill and the load lines were printed collinear with the applied tensile force direction. These results mainly show that factors like choosing to use PETG instead of PLA and less infill (our 20% vs. their 50%) were beneficial for our team in recording slightly higher average ultimate strengths while being slightly lighter, which would be a positive characteristic to have if we wanted to mass produce the shovel handle. However, possibly choosing to find a way to print the shovel in a configuration that allows most of the load lines to be collinear seemed to be most effective for their testing results.

Shovel Handle Model & FEA

A model of the snow shovel handle was made in SolidWorks and an FEA was performed on it. A distributed load of 100 lbf was applied to the top half of where a person would grab the handle. The hole where the shaft will be inserted was fixed. This imitates a person pushing the shovel and the handle being fixed in place to the rest of the shovel. Different plots were generated to determine the different stresses and the displacement of the handle. An engineering drawing of the shovel handle can be found in Appendix A8.

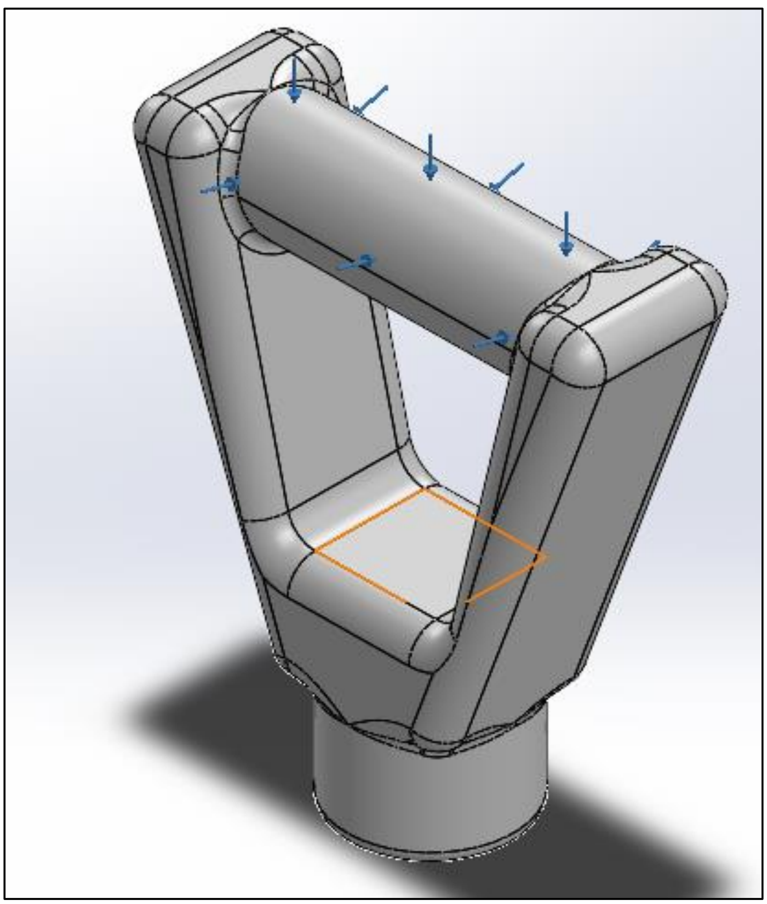


Figure 4: Model of Shovel Handle

The FEA analysis shows the handle will not fail under a 100 lbf load. The maximum shear stress was in the XY plane and was found to be 128.4 psi. A maximum von Mises stress of 349.4 psi. These loads do not exceed the tensile strength of 8311 psi. The stress was concentrated mainly under the ends of cylindrical portion of where the distributed load was being applied. It should be noted that the displacement experienced by the handle was minuscule. The results of the study confirm the handle can withstand the loads that would be applied to it in a real-life situation. Plots for different results in the study can be seen in Appendix A3 – A7.

Handle 3D Print & Documentation

Based on the results from the tensile testing and modeling the loading using FEA, we decided to print a final model using the gyroid infill with the original print parameters of 20% infill and PETG filament as seen in Figure 5 below. The print took roughly 10 hours to print and ended up weighing about 76 grams (2.68 oz.). This decision was made based mainly on the material characteristics found in the tensile testing. Although the concentric infill had a higher ultimate stress of 22.6 MPa vs the 21.6 MPa for the gyroid infill, the amount of strain the gyroid test was able to withstand far surpassed any of the other configurations. Also, the ultimate strength difference was very minimal compared to the rest of the tests and still very small compared to the concentric infill, with the added benefit of high % elongation at failure. These characteristics make for an equally strong but long lasting piece of equipment to be used in a real life setting.

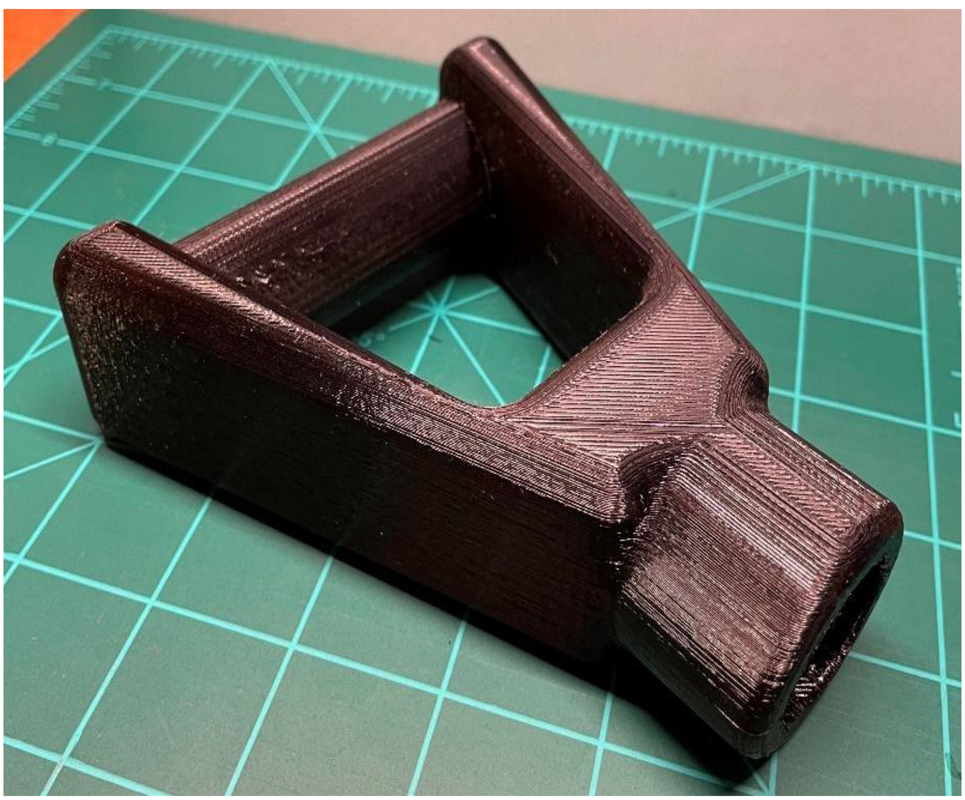


Figure 5: Final printed shovel with Gyroid infill using PETG filament

Shovel Handle Manufacturing Study

Snow shovel handles can be made from a variety of materials. The most common being stainless steel, wood, and plastics. These materials are chosen due to their durability and cost. Stainless steel is also a metal that is resistant to corrosion. Plastics are not as strong as stainless steel, but they are cheaper than metal and can be very durable depending on the type used.

Metals tend to rust when exposed to the air. Stainless steel, however, has a very high resistance to corrosion compared to other metals. Corrosion resistance is an important factor when designing a shovel handle because it will be exposed to the outdoors on a frequent basis. A stainless steel shovel handle would have to be either cast or manufactured from the stock. This would result in a high-strength product that would most likely exceed the lifespan of the actual shovel. The most common variants of stainless steel used when making shovel handles are 201 and 439 stainless steel.

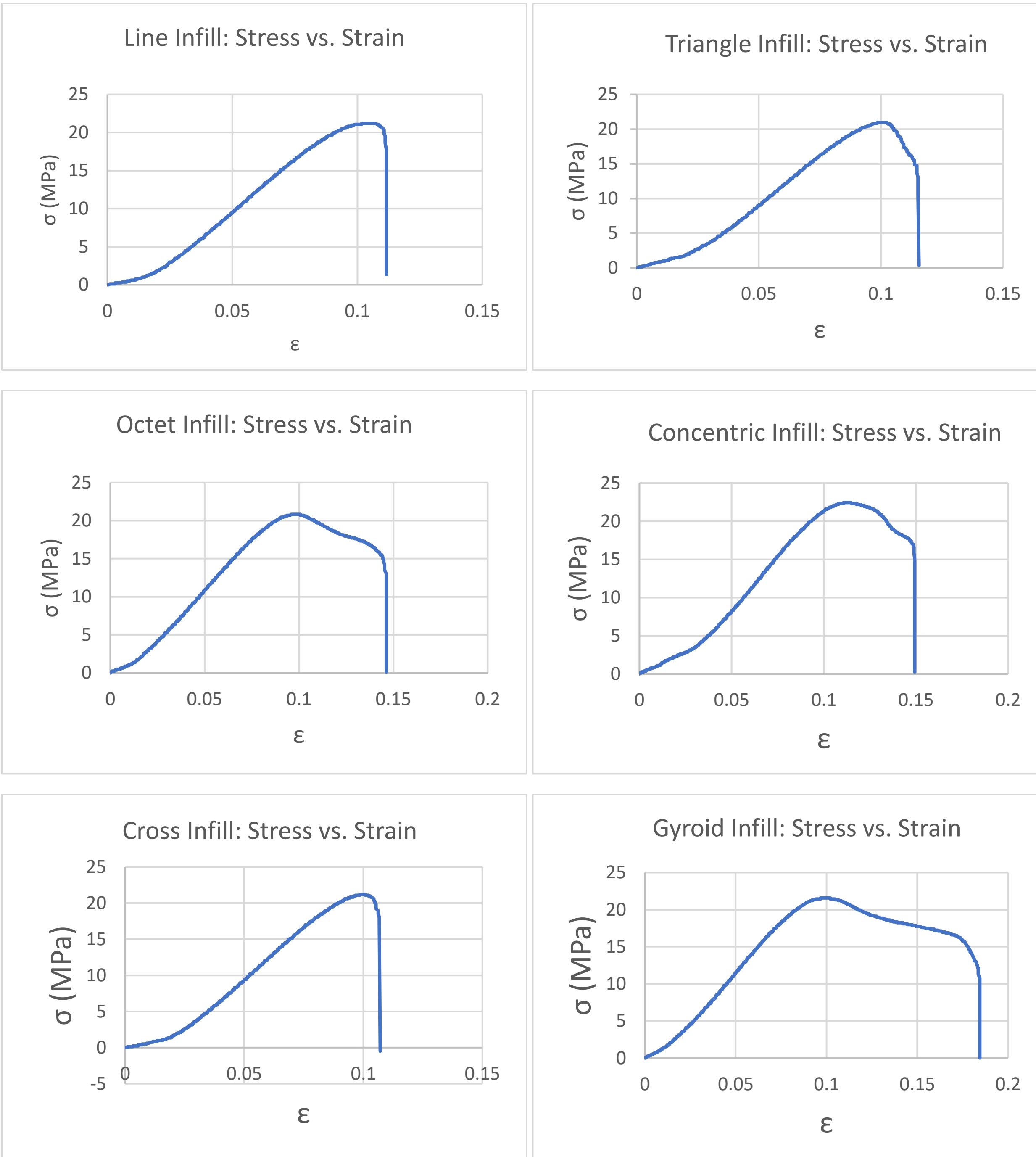
Wood is a cheap and easy to work with material. Most shovel handles that use wood usually have some sort of plastic or metal along with it. The wood is mainly used for the area that a person would actually grip the handle. This would be carved using a wood lathe. Wood is a sustainable resource that can provide a considerable amount of resistance before breaking. However, it is susceptible to rot. When exposed to humid weather, this process could be accelerated. Wood is easily replaceable but has the potential to have the shortest lifespan of the listed materials.

The material used in the 3D printed shovel handle was a PETG filament. Depending on the infill orientation, different strengths were produced using the same material. It was decided to use a gyroid infill due to its high strength and ductility when tested. Shovel handles manufactured using steel do not have the benefit of being able to use different infill patterns.

Polylactic acid (PLA) is also a common material used in the manufacturing of snow shovel handles. It is cheap, widely available, and can be used in 3D printing. The comparison used previously of our PETG and another team's PLA proved that PLA yields a slightly higher ultimate tensile strength. It is important to note that the other team had a 50% infill while ours had a 20% infill. This also could have had an effect on the strength of the materials.

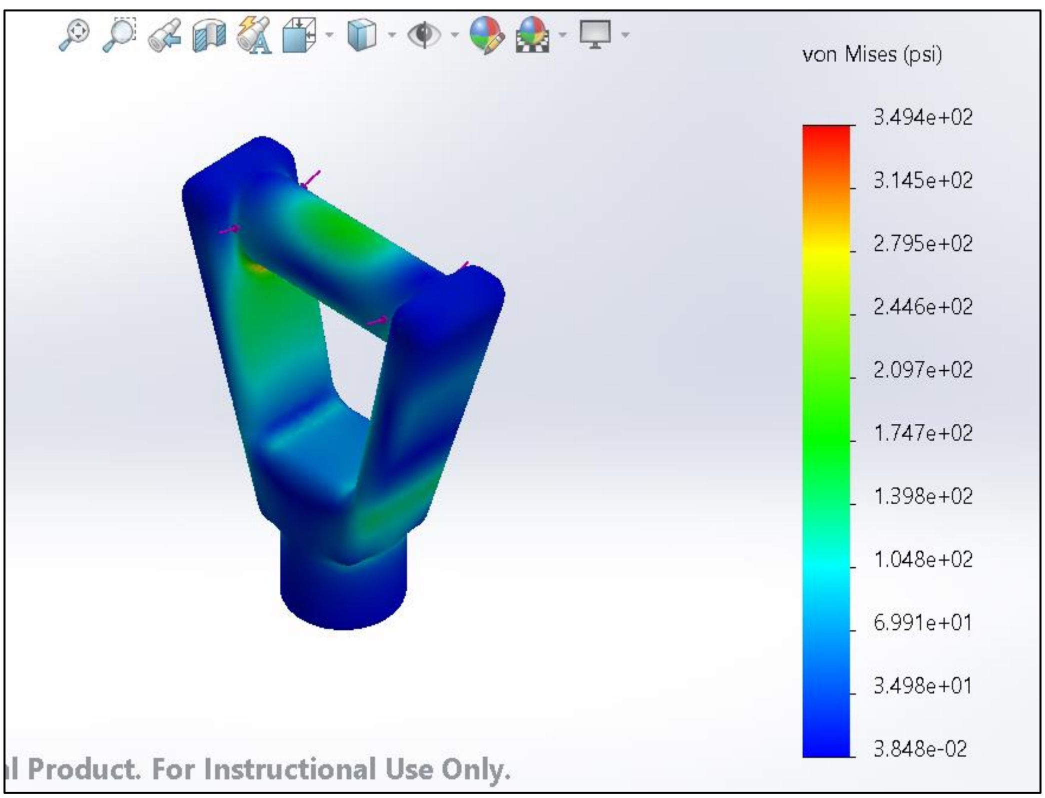
Plastics are a versatile material that can be milled out of a stock, printed, or even injected into a mold. In this project, 3D printing was used to produce a snow shovel handle. Stainless steel would yield a much higher ultimate tensile strength when compared to any plastic that would be used. However, stainless steel is much more expensive and not as versatile as plastics. Additionally, wood is a cheap and strong resource, but is susceptible to rot. It also is generally accompanied by either metal or plastic. By using PETG, our team accomplished designing and producing a shovel handle that can withstand the forces that would be applied to it. PLA could have also been used, but PETG was chosen due to its low melting point and higher ductility characteristics when compared to PLA and ABS filaments.

Appendix:

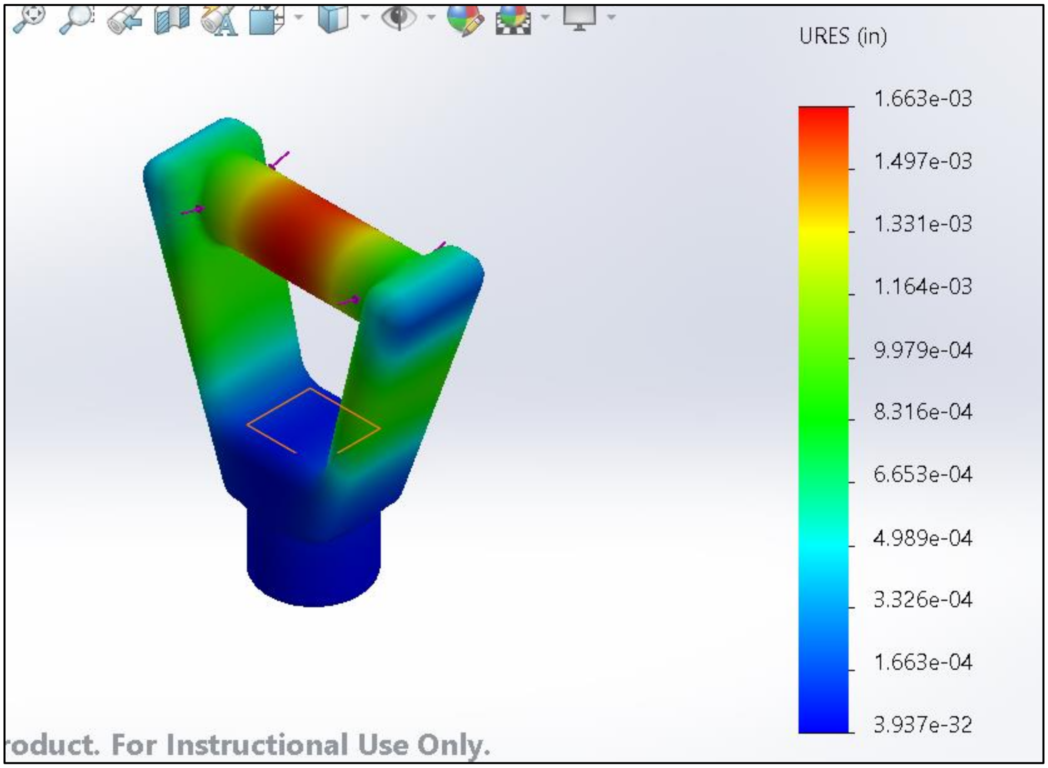


A1: Independent stress-strain plots for each infill pattern

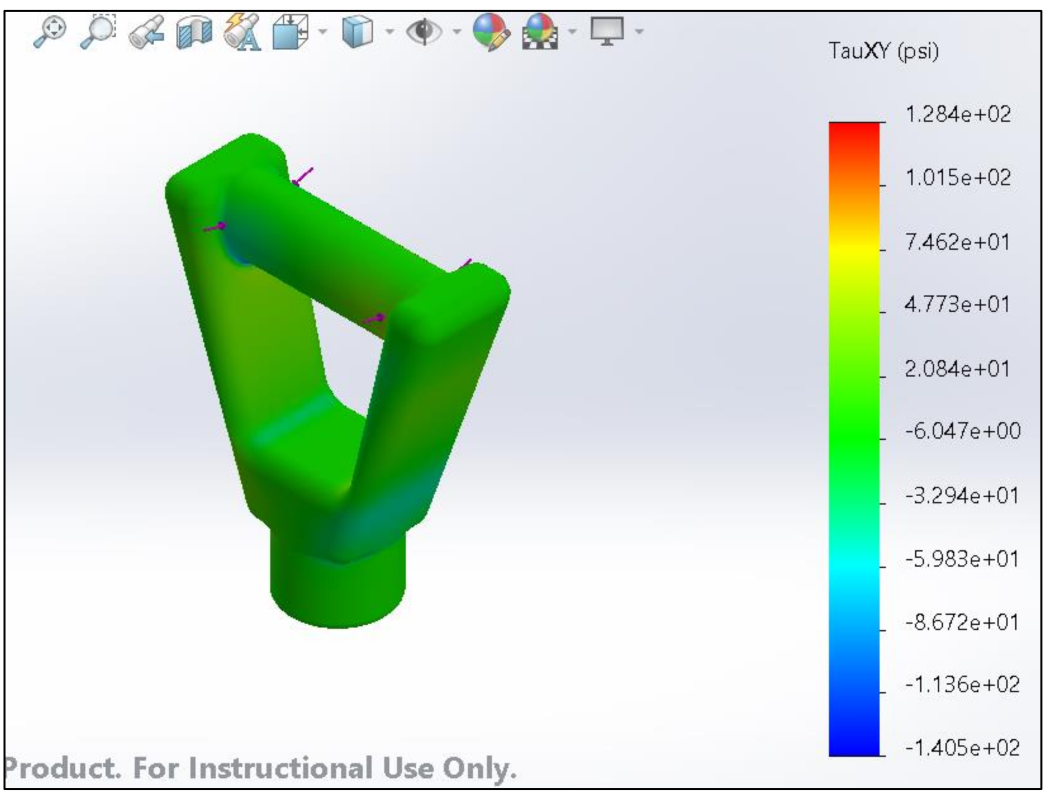
A2: Dog bones before and after testing, in order of testing



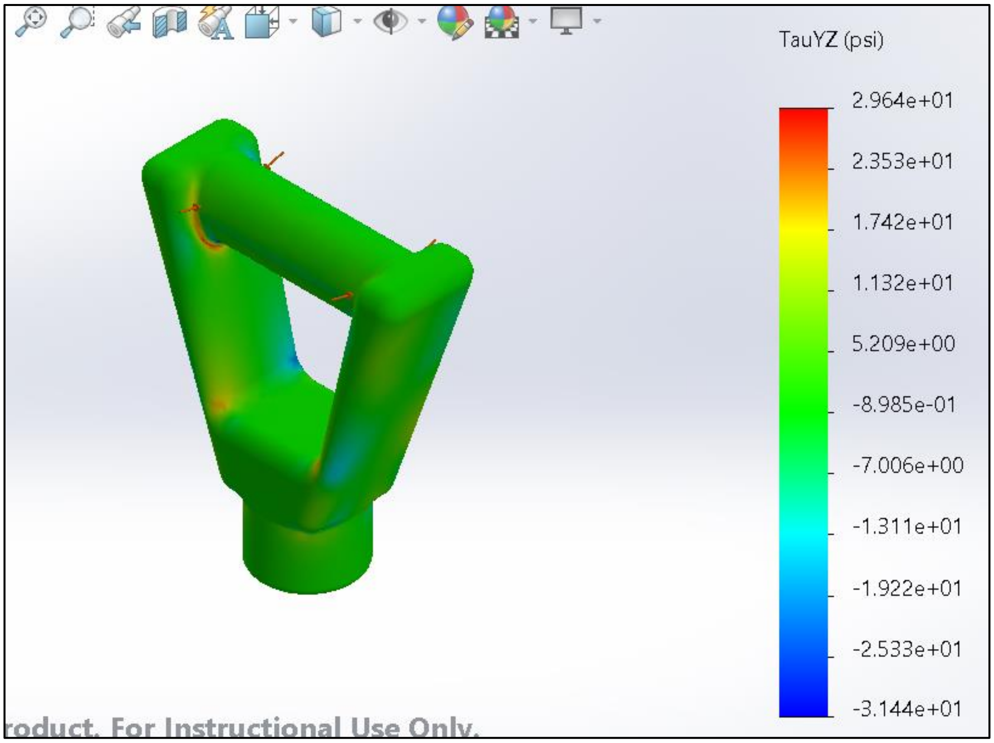
A3: von Mises Stress plot



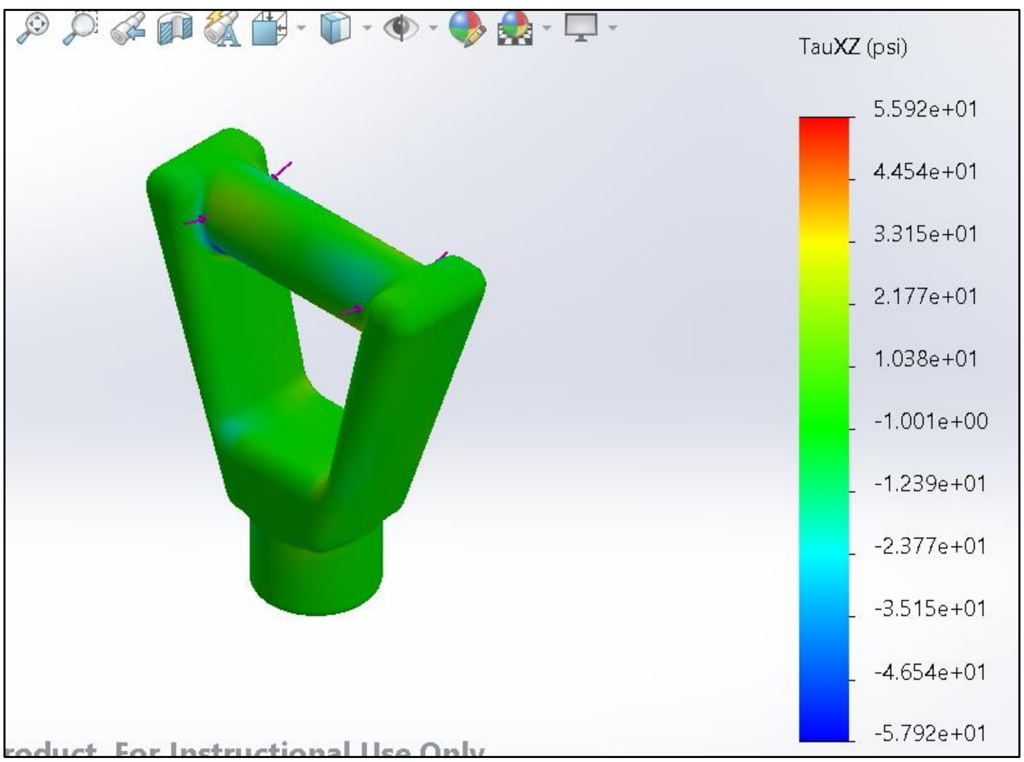
A4: Resultant Displacement Plot



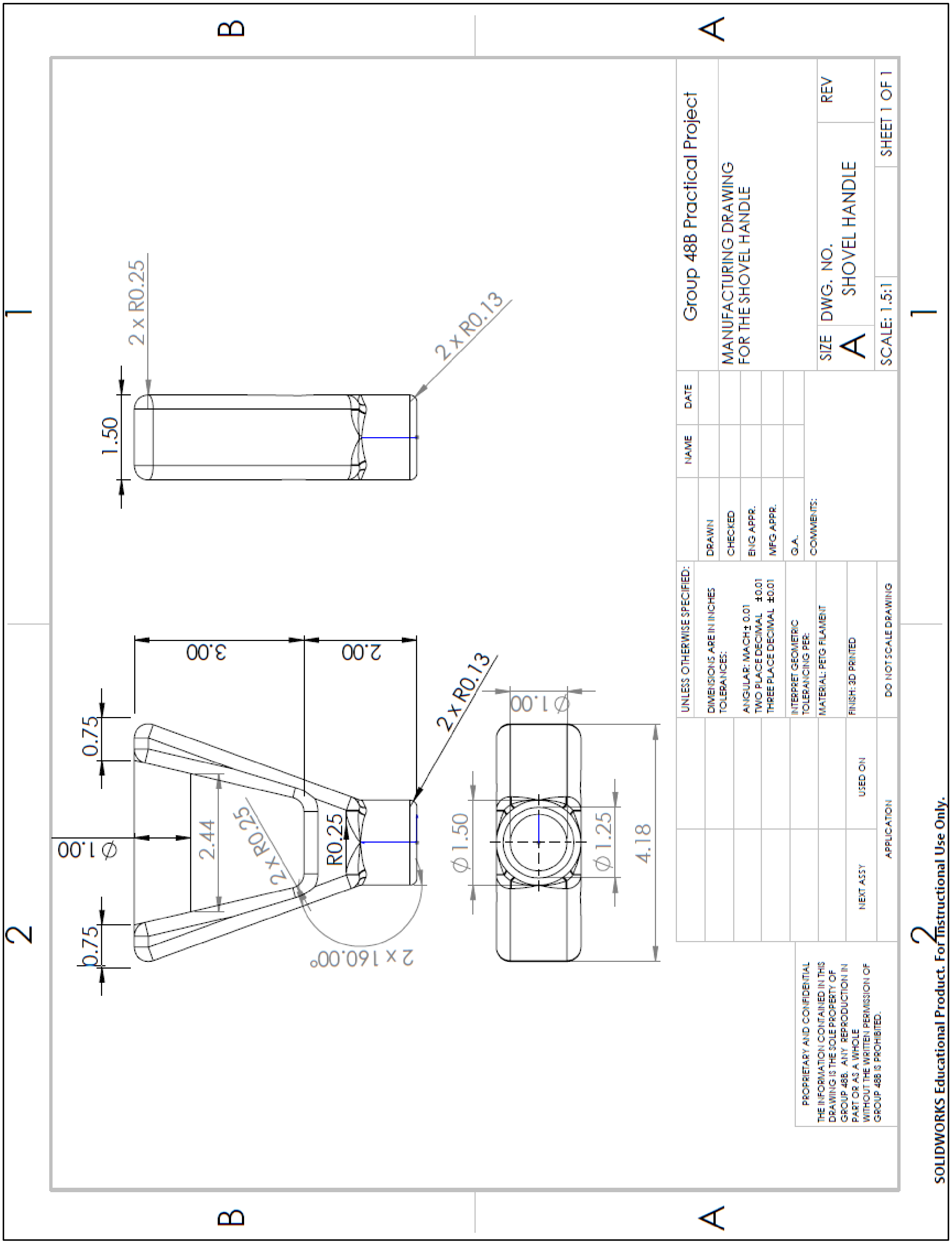
A5: Shear Stress in the XY Plane plot



A6: Shear Stress in the YZ Plane plot



A7: Shear Stress in the XZ Plane plot



A8: Manufacturing drawing of the shovel handle