# FAILURE ANALYSIS LAB

**Isabella Panzica, Austin Reth, and Audrey Shultz**
**Department of Engineering and Physics**
**Elizabethtown College, Elizabethtown, PA**

## MOTIVATION AND BACKGROUND

The following failure analysis is the evidence behind the Scooper vs. Customer lawsuit. A brief background of the case is as follows. The defendant's ice cream stand was serving a large crowd of people on the first of April when their ice cream scoop broke. A few minutes after serving the ice cream, a woman had a complaint that a piece of metal had been found in her ice cream cutting her tongue.

The owner of the shop was called upon, and an altercation had started between the prosecutor and defendant discussing where the metal shard had originated. This resulted in a lawsuit against the ice cream shop, which is why the analysis of the aforementioned ice cream scooper came into occurrence. The ice cream shop wants to prove that the metal shard did not come from the ice cream scoop, but originated in the ice cream itself henceforth making the lawsuit Hershey’s problem and not the shops.

The scoop is a basic design with a lever to push the ice cream out of the scooper. The scooper was made to hold 4 ounces of ice cream. However, it is undetermined how much force the scooper can undergo before the ultimate stress is reached breaking the weld that holds the bowl and shank together. Another motivating factor is the shop wants to save money as they go through at least seven scoopers a month. At five dollars a scooper, that costs $35 a month or $420 a year on scoopers alone. If they can find out why the scooper broke, then they can prevent this action in the future and save money on buying scoopers.

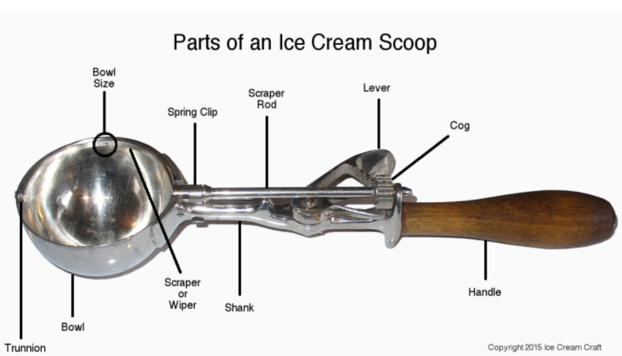


Figure 1: Diagram labeling the parts of an ice cream scooper similar to the type being analyzed. Taken from icecreamcraft.com

## METHODS

To begin this analysis, we first simulated the scoop on Autodesk Inventor. With doing this, we were able to reproduce the estimated amount of force applied to the scoop recreating the break in the weld. Although we were unable to duplicate the strength of the weld accurately, we were able to deduce that the stress in the handle mount is where the maximum is located. Since the weld is weaker than the tack weld of the handle mount, this caused the weld to break.

We also used an Infinity 1 Nikon microscope to take a closer look at the break. This was able to tell us if there was fatigue in the stainless-steel weld. Also, it was able to tell us if the scoop had lost any shards of metal, or if it was a clean break.

Another thing we did to analyze how the scooper broke was to take a cracked scooper close to breaking, applied a force to it and watched what happened at every part of the scooper. By doing this, we discovered that three things happen that leads up to the scooper breaking: a crack develops making the bowl bend backward when a force is applied, the scooper’s pieces fall apart, and the bowl continues to bend back until it detaches itself from the shank.

Falling apart is a term that the store employees gave one of these stages of failure. This failure stage is elaborate and starts with the weld cracking while a force is applied, then the bowl slightly bends backward which pulls the scraper rod upwards. When the lever is open the cog of the scraper rod cannot move up enough to pop the scraper rod out of the hole holding the scraper lever in place, preventing the scooper from falling apart. Though when the lever is closed the cog of the scraper rod can raise 3mm and pop out of the hole holding it in place. The cog of the scraper rod then unlock itself from the lever and detach itself from the scooper, causing the lever and the lever spring to fall off of the scooper.

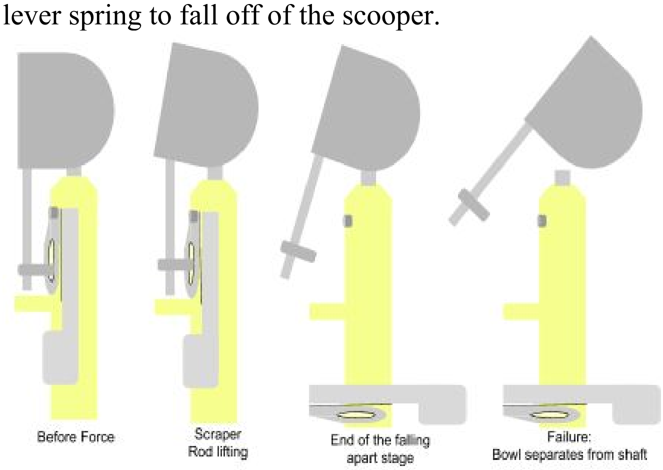


Figure 2: The visuals of the stages of the scooper falling apart.

## ANALYSIS

### Theory

#### Required Strength:

Both the weld and the scooper are made of stainless steel, by knowing this the material properties of the scoopers can be found and used in the strength and safety factor calculations.

Table 1: Stainless Steel Material Properties

| Material | Modulus of Elasticity | Tensile Yield Strength | Poisson's Ratio | Coefficient of Thermal Expansion |
|---|---|---|---|---|
| Stainless Steel | 28103ksi | 30 ksi | 0.27 | 9.610-6/F |

Another piece of information that needed to be analyzed in order to find the strength and safety factor was the forces acting on the ice cream scooper. This was done through the free body diagram in Figure 4. Through the free body diagram, the combined loading was identified and then calculated, this is seen in Figure 5. The combined loadings identified were torsion, bending, and force. From the combined loading the stress tensor and safety factor were then calculated in Figures 5 and 6 in Appendix A. In the calculations for the ice cream scooper one of the assumptions was that the force a person puts on the ice cream scooper was five pounds. This may vary in real life depending on the hardness of the ice cream but is a reasonable amount of force for scooping ice cream. When using five pounds as the force being put on the scooper, the safety factor was 3.73, and therefore the amount of force that causes failure is 18.65lbs.

Unfortunately, ice cream is scooped using with about 60 degrees of elbow flexion, and with that range of motion, the average arm strength is 20lbs when using the dominant hand and 18 pounds when using the non-dominant hand [1]. Also, muscles get stronger after using them on a regular basis resulting in the employees scooping the ice cream to have slightly stronger than average arm strength. So even if an employee is not using their dominant hand, they might build muscles in their arms and be able to increase their arm strength. Also many ice cream store employees say they have to scoop with all their strength to scoop certain flavors. Which proves that the ice cream workers are using more than 18.65lbs of force while scooping ice cream, which then causes failure in the ice cream scooper.

#### Forms of Failure:

The factors that affected the scooper was it's a variation of temperature is underwent when it went from lukewarm dip well water to the cold temperature of the ice cream. Temperature change affects the strain of the scooper, which is the change of shape of the material after a force is applied. Cold temperatures make metals more brittle and reduced the material's elasticity. This makes the material easier to break because it reduces the material's safety factor.

Torque is another factor of failure of the ice cream scooper because of the way that the ice cream scooper is held since the hand applying the force to the ice cream scooper in located on the handle close to the lever. Then the ice cream that is being scooped is a constraint acting on the bowl of the ice cream scooper. Since torque is the force applied to the object times the length between the force and the constraint, it is larger than if the force was applied closer the bowl.

Constraints is another factor of failure. The bowl of the scooper had two main constraints, the shank, and the scraper rod. When the scooper broke, it broke along the weld connecting the bowl and the shank yet the scraper rod didn't break. During the failure stage of falling apart, the scraper rod unlocks itself from its hold on the lever. This causes the scraper rod to detach itself from the scooper and to be no longer able to act as a constraint of the bowl.

Metal fatigue is another factor of failure since on a given day a scooper could be used a hundred times. Most scoopers last around a month, making the number of uses for the average scooper ranging from 2800 to 3100 uses. Evidence of cracks is seen circled in Figure 3, located in the broken weld of the ice cream scooper.

Figure 3: Cracks in the weld of the broken ice cream scooper

Bending is another factor of failure for the ice cream scooper since the scraper rod, shank and shaft are all circular beams. When the weld is not cracked the ice cream scooper can bend. This is seen in the scraper rod while it is being lifted up since the rod is a circular beam that has forces on its ends. The bend of the scraper rod is significant since the bending allows the scraper rod to pop out of the hole that was keeping the rod in place.

**Finite Element Analysis**

For this analysis, we did two different analyses. The first was an analysis of just the bowl attached to the shank since that is where the ice cream scoop broke. We then added the scraper rod to the assembly to see how that affected the stresses on the scoop. Since the position of the scrapper changed its effective length, we did two different models. One with the full length of the scraper rod, simulating when it is in a locked position and one where it was a half inch shorter imitating when the scrapper was engaged during scooping.

For all the analysis the shank of the scoop was a constraint, and in the cases where the scraper rod was included, it was constrained as well. A 5 lb force was applied to the lower half of the edge of the bowl. This simulated the fact that the whole scoop is not in contact with ice cream when scooping ice cream. For all the scoops tested, the displacement did not vary so Figure 12 in the Appendix, depicts the overall displacement of the bowl with the applied force. A 5 lb force was chosen since it gave a minimum safety factor of 1.15 and it was figured that an ice cream scoop would not have a significant safety factor see Figure 13 in Appendix.

Table 2: This table shows the safety factor and Von Mises stress for each of the three different models that we analyzed. The only variation was the presence and length of the scrapper rod.

| | Minimum Safety Factor (μl) | Max Von Mises (ksi) |
|---|---|---|
| No Scraper Rod | 1.15 | 31.41 |
| Short Scraper Rod | 1.36 | 26.72 |
| Long Scraper Rod | 1.35 | 26.77 |

As is evident in Table 2, adding the scraper rod on the safety factor and Von Mises stress. The safety factor increases and the Von Mises stress decreased. However, the length of the scraper rod had almost no effect. The safety factor varied by 0.01μl and Von Mises differed by only 0.05 ksi. Images of the various safety factors can be found in the Appendix Figures 13-15. For the different pictures for the three Von Mises stress refer to Figures 16 -18 in the Appendix.

The FEA put the highest point of stress where the rod attached to the bowl, however, the scoop broke where the bowl was welded to the shank. Even after separately building each piece and then assembling them, the highest stress and lowest safety factor were where the rod met the bowl. This may be attributed to the materials performance under different temperatures. Since we could not alter the temperature of the scoop in the FEA, we could not wholly imitate the scenario that leads to failure. The cold temperatures may have led to the weld contracting more than the other material which eventually leads to failure of the weld. So, with the FEA is an excellent tool for analysis stresses, the lack of temperature prevented an utterly accurate recreation routine use in the ice cream shop.

**Visual Inspection**

In the images below, an up-close picture of the break is shown in Figures 3 & 7-11. It is evident from the microscope photos that there is previous cracking before the final break as there are signs of cracking at the breaking point of the weld. More than likely, this resulted from too much force being applied to the scoop consistently. The break was brittle because the scoop is made of stainless steel. If you look closely, you can see where the weld disconnected from the handle and scoop which caused the breaking. Overall, the break was clean, and there would be no noticeable chips of metal resulting in this failure.; the pieces of metal from the weld were microscopic and would not result in an injury to the mouth.

**CONCLUSION AND RECOMMENDATIONS**

After reviewing all the data collected from the various analyses that were performed, there are several factors at play that lead to the failure of the ice cream scoop. One of the more prominent factors being the bending of the shank during use. Between the constant repetitive use and the changing temperatures, the weld weakened over time and eventually failed. While the FEA suggested that it would fail where the shank was welded to the bowl, the scoop broke where two pieces of the shank were welded together. This can be attributed to the small size of the weld that connected the two parts of the shank compared to the larger weld that held the shank to the bowl.

Also with the scraper rod engaged in scooping the ice cream, the scraper rod could pop out of place. Once the scraper rod pops out of place, extra stress is placed on the shank can. Over time this causes a crack to form and grow, eventually leading to the failure of the smaller weld.

Based on the above analysis there are several ways that future failure of ice cream scoops can be prevented. The simplest solution would be to train the staff to not engage the scraper until after the ice cream has been scooped. This would prevent the scraper rod from popping out of place in the first place. Another solution would be to use a larger weld to hold the two pieces of the shank together. A larger weld surface would decrease the overall all stress and increase the life of the ice cream scoop. Eliminating the weld entirely and making the shank one solid piece would be the most effective way to keep the ice cream scoop from failing there.

**REFERENCES**

[1] [1] Rhonda Rose, Man-systems Integration Standards Journal Volume One Section 4 Human Performance Capabilities. 2008

[2] EGR 264 Strengths of Materials Lab handout, Failure Analysis

**APPENDIX A:** Hand Calculations

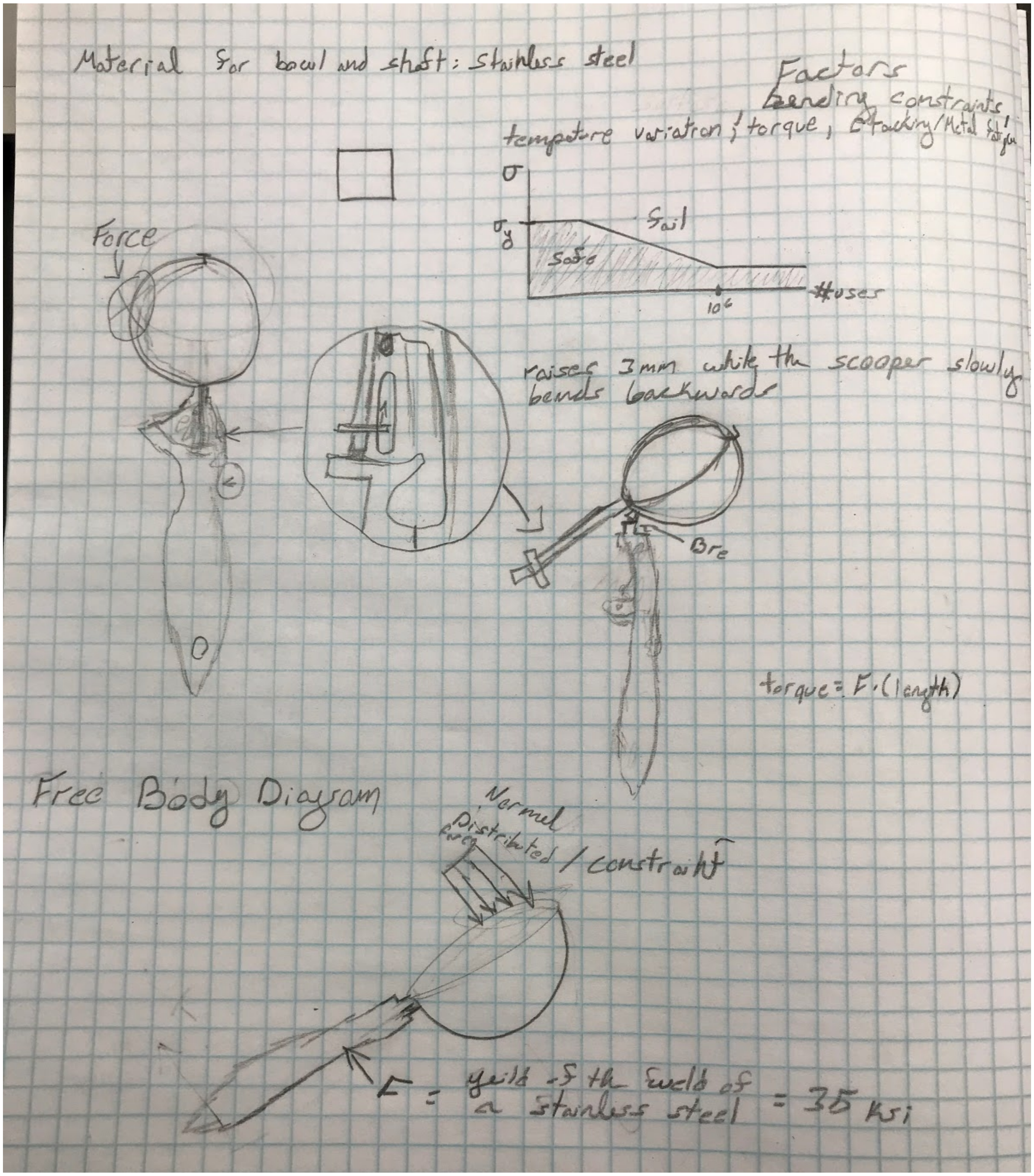

Figure 4: displays the free body diagram of the scoop with a maximum load before failure.

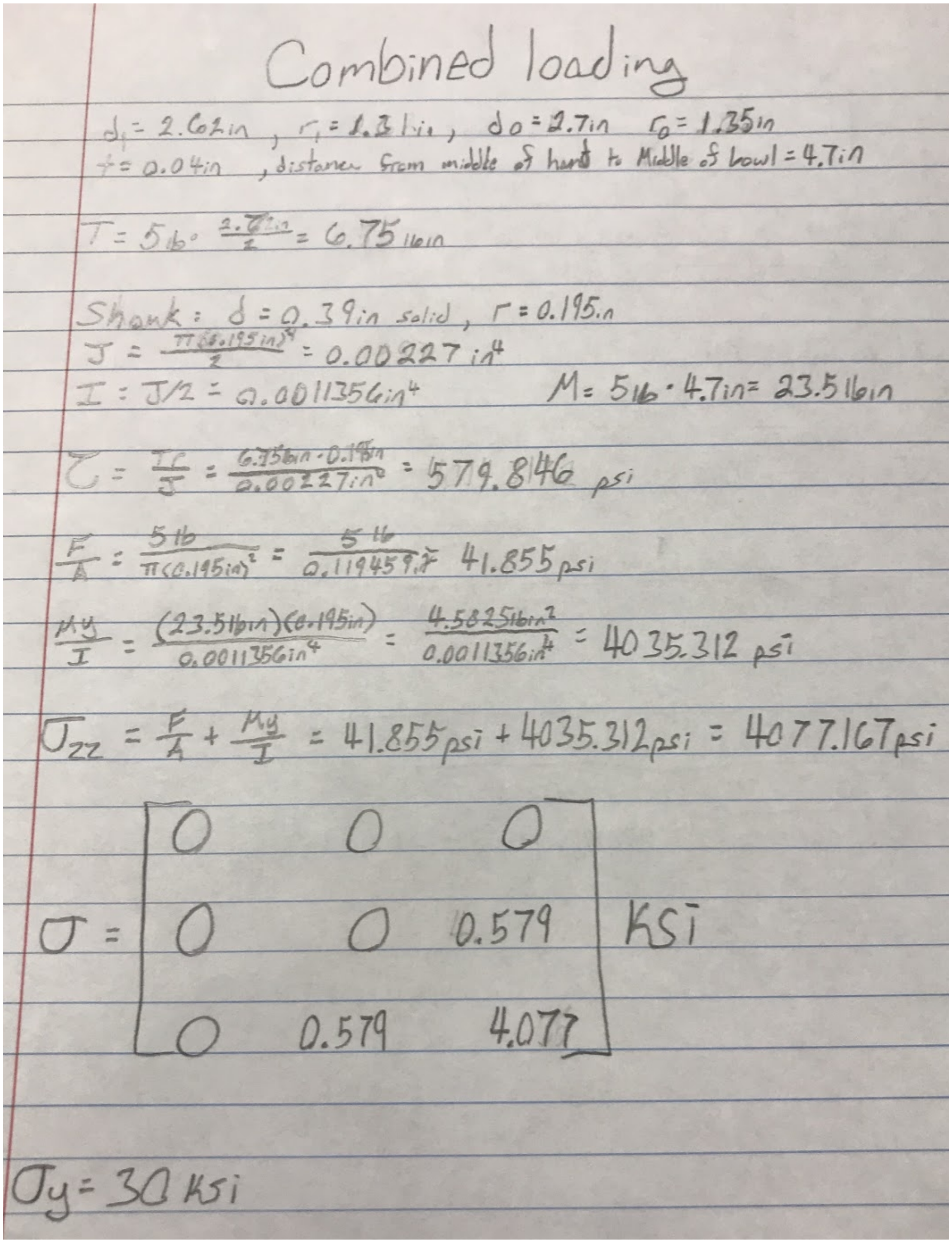

Figure 5: Hand calculations for the combined loading and stress tensor matrix.

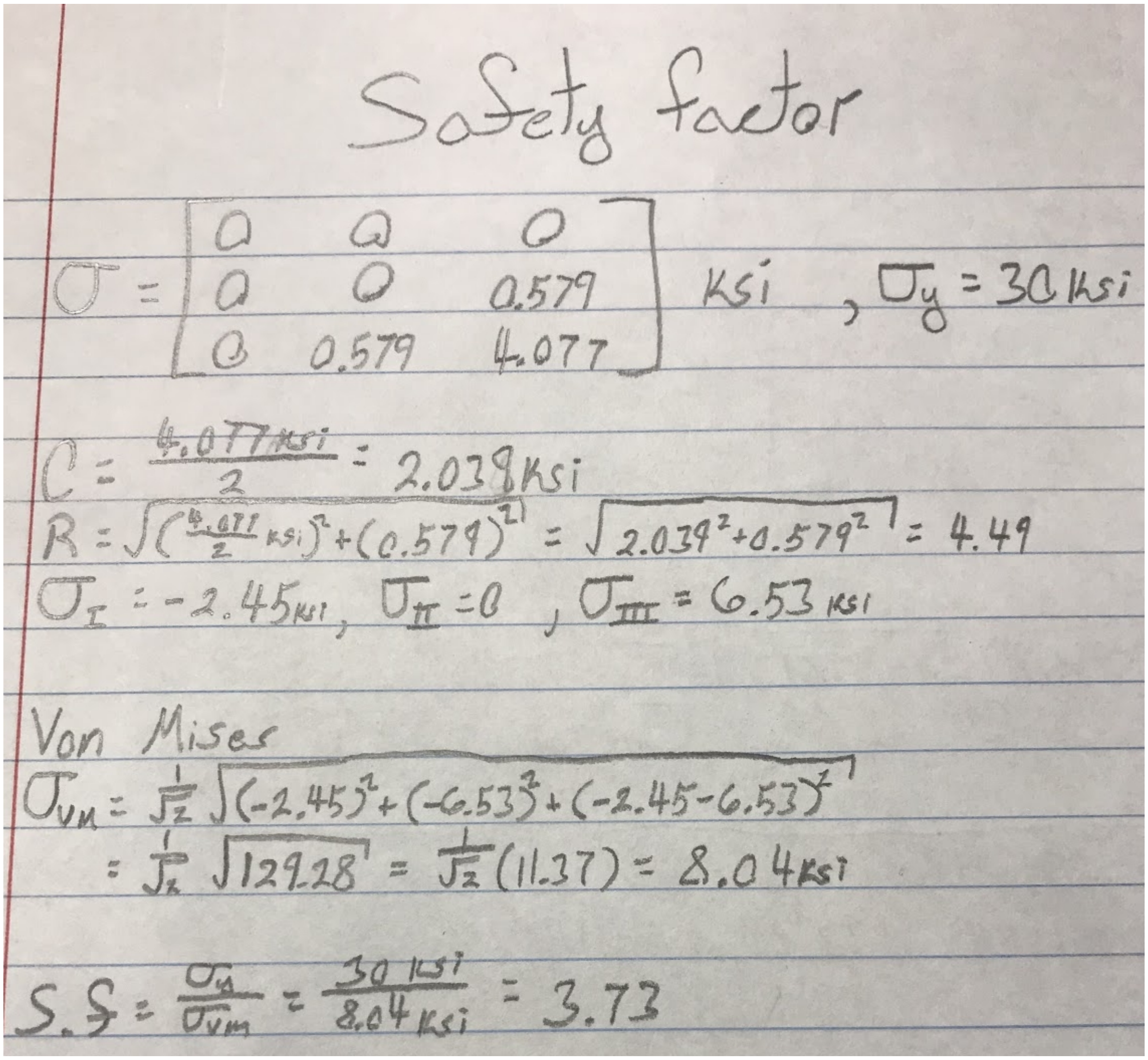

Figure 6: Hand calculations for the Safety Factor of the ice cream scoop.

**APPENDIX B:** Microscope Pictures

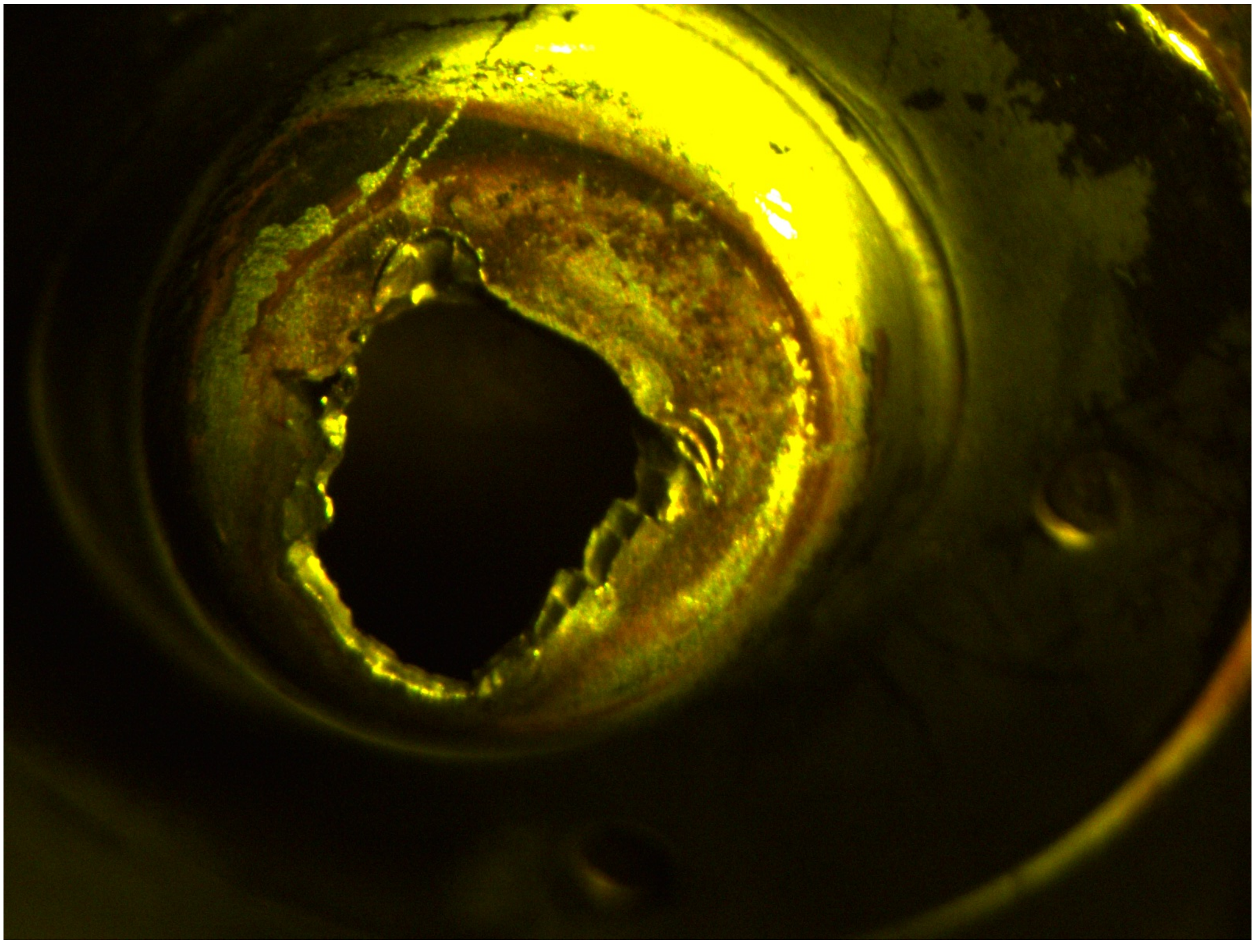

Figure 7: Displays the microscopic image of the scoop, where the weld disconnected from the bowl.

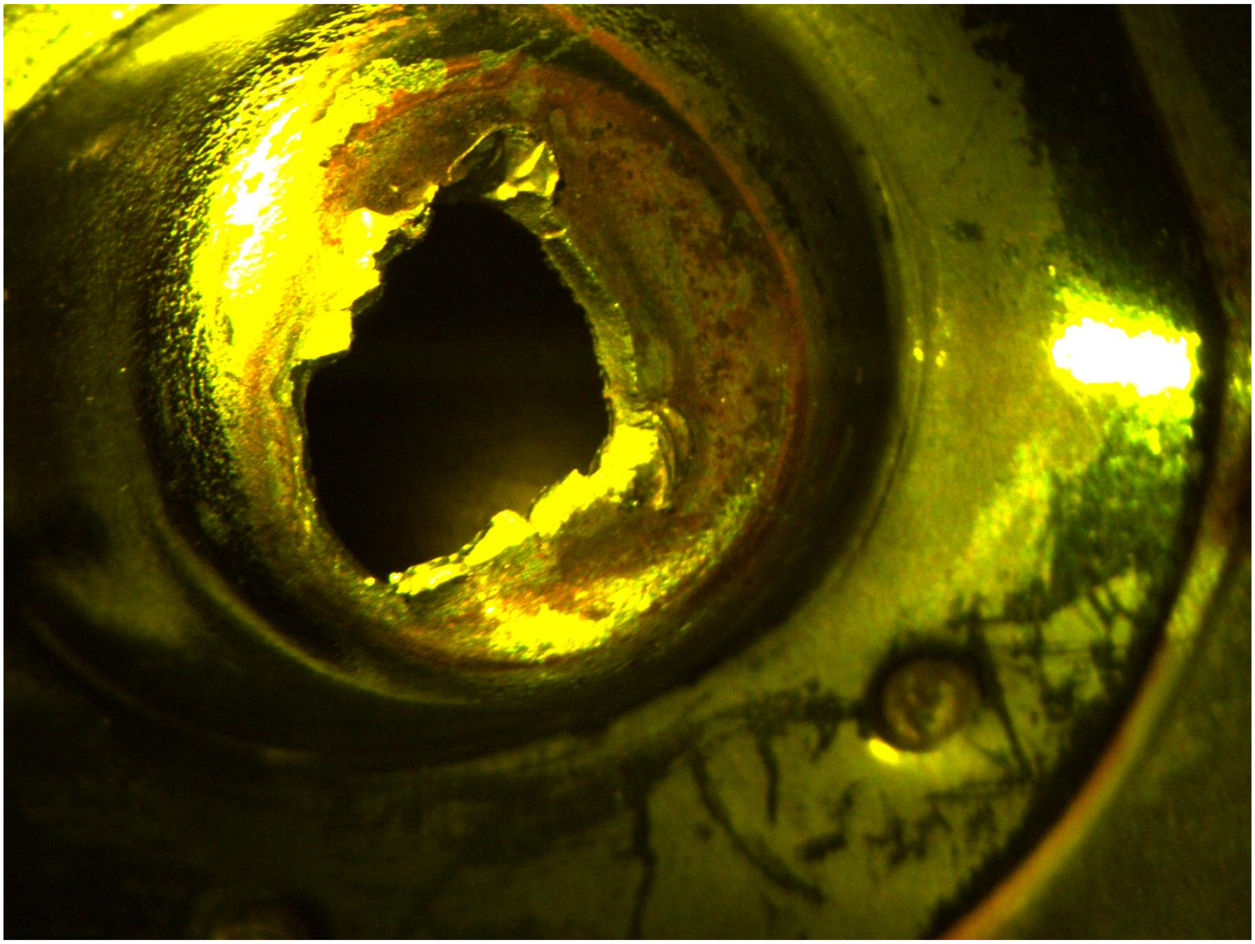
Figure 8: Another angle of where the weld broke off of the shank.

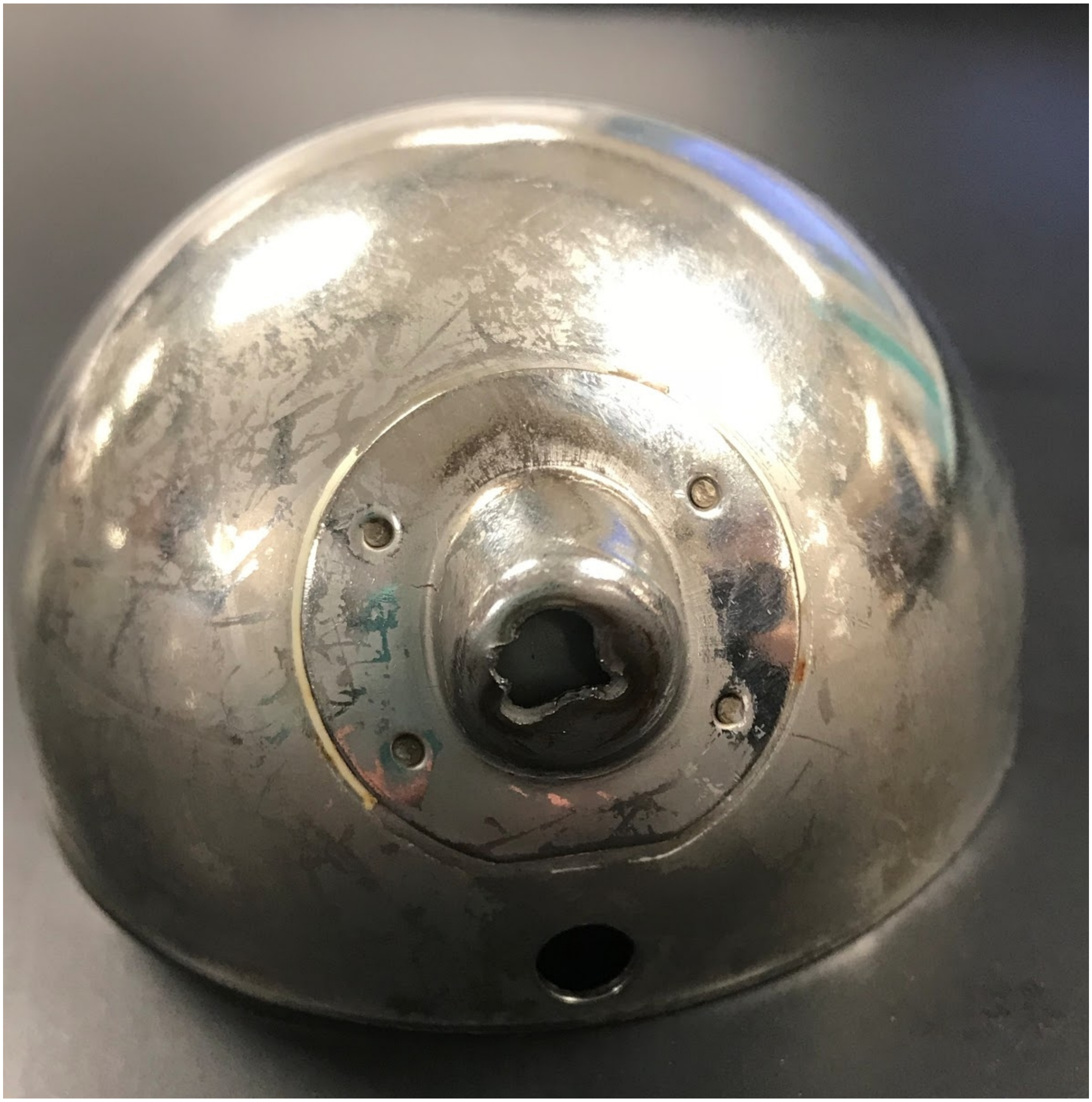

Figure 9: This is an image of the ice cream scoop’s bowl that broke off of the handle.

Figure 10: This picture is an image of the handle and shows the size of the weld relative to the size of the handle of the ice cream scoop.

Figure 11: This is a side profile image of the weld that connected the bowl to the handle of the ice cream scoop.

**APPENDIX C:** Finite Element Analysis

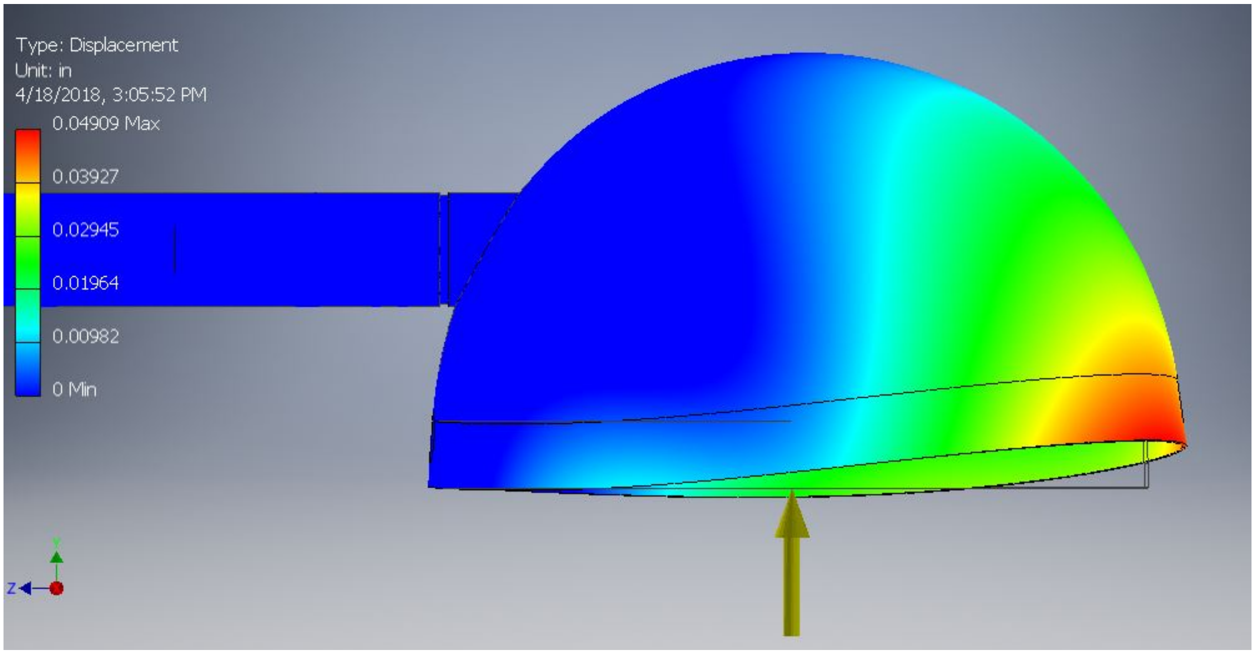


Figure 12: This figure shows the displacement of the ice cream scoop with a 5 lb force applied to the lower half of the bowl's edge. This is from the simulation without the scraper rod. The addition of the scraper rod had no impact on displacement.

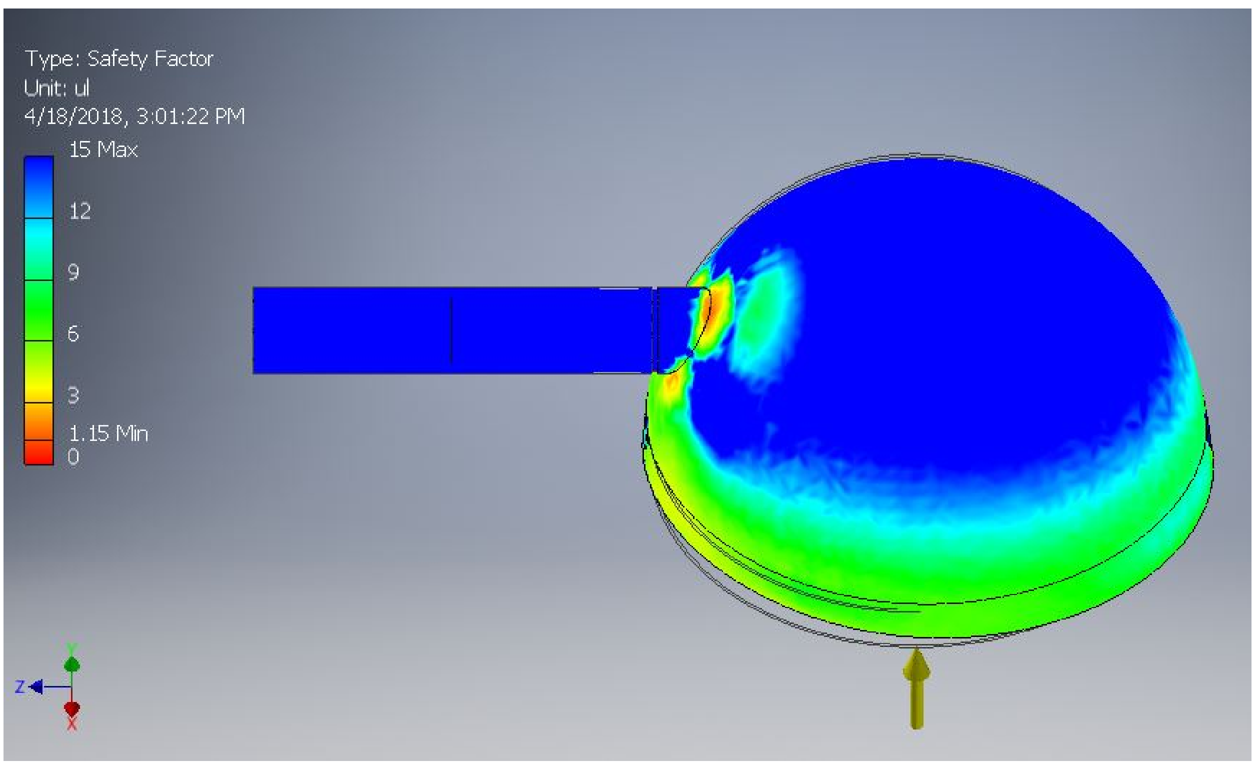


Figure 13: This figure shows the safety factor of the ice cream scoop with the 5 lbs of applied force. The minimum safety factor occurs where the shank meets the bowl.

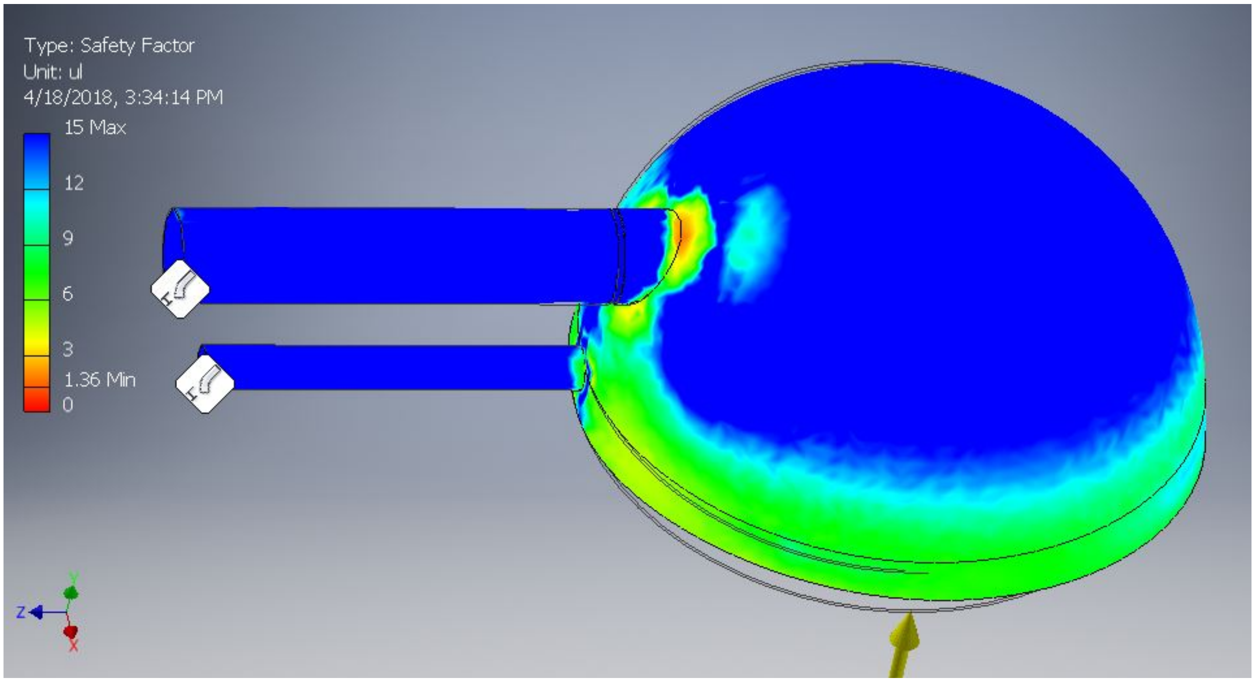

Figure 14: This figure is the safety factor for the ice cream scoop with the shorter scraper rod added. It did not affect the location of the minimum safety factor, but it did raise the minimum safety factor.

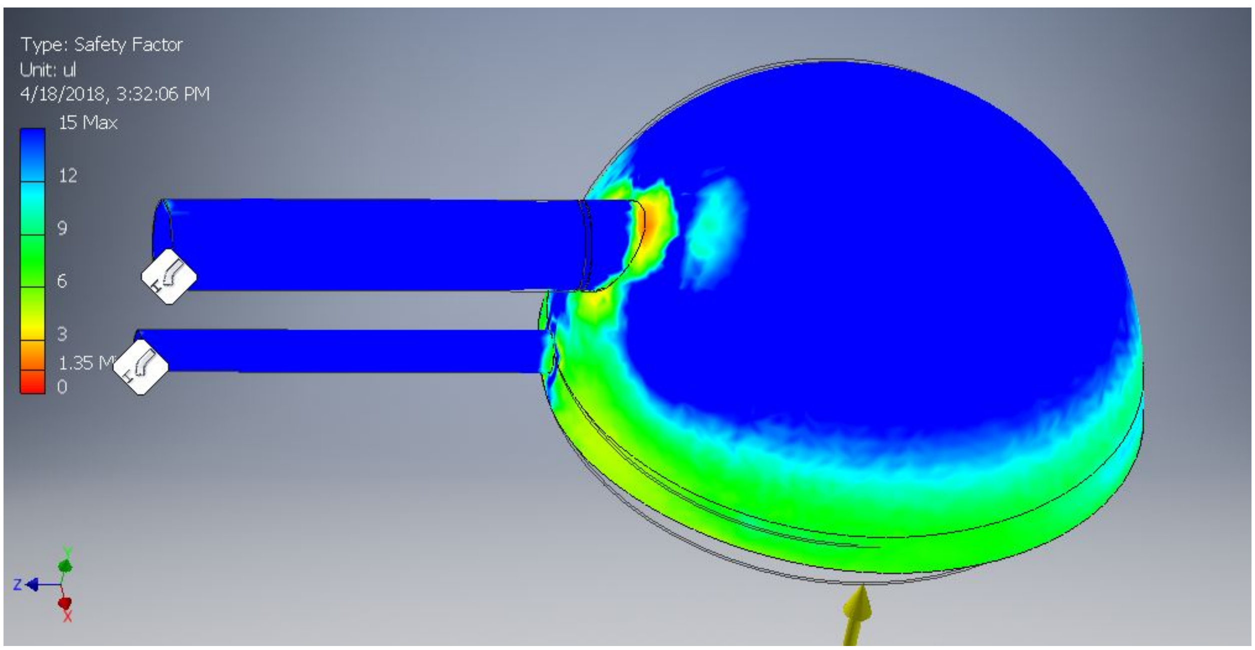

Figure 15: This figure displays the safety factor for the ice cream scoop with the long scraper rod. This had the same effect on the safety factor as the shorter scraper rod did. It did not move the location of the minimum safety factor, but it did raise the minimum safety factor.

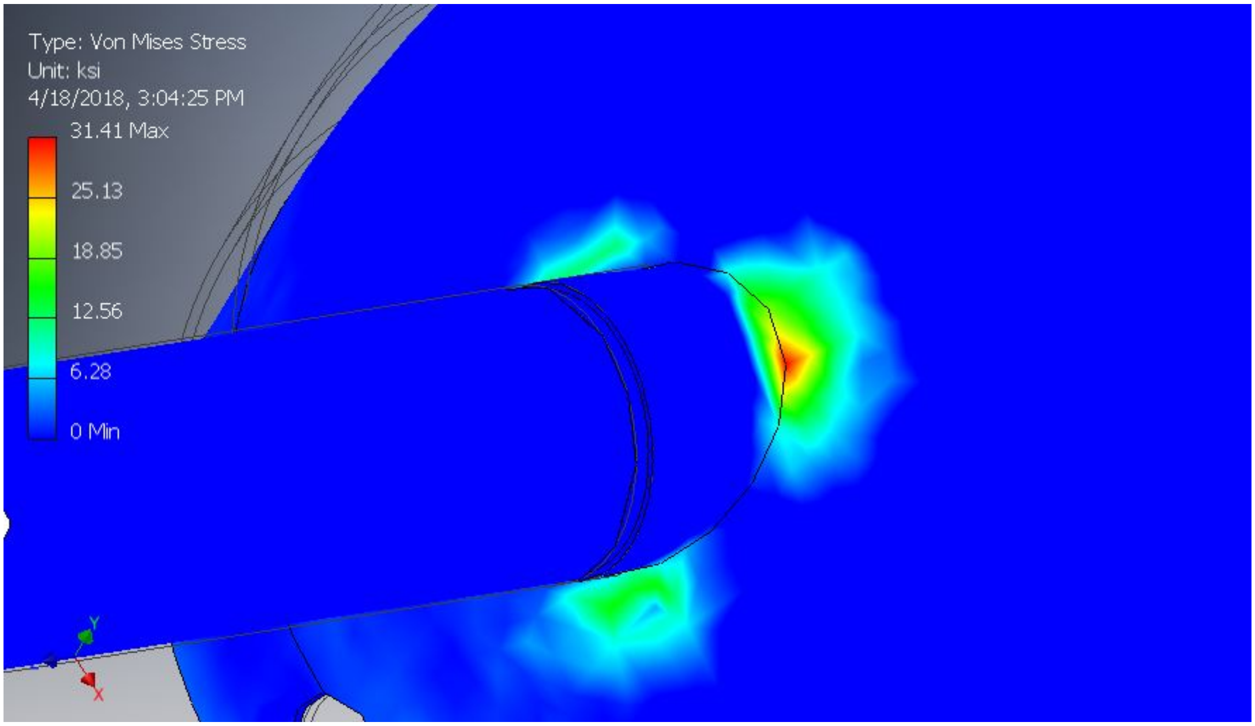


Figure 16: This figure is a close up of the area of max Von Mises stress on the ice cream scoop without the scraper rod. This figure shows how the stress was concentrated right where the shank meets the bowl. The rest of the bowl experienced little to no stress.

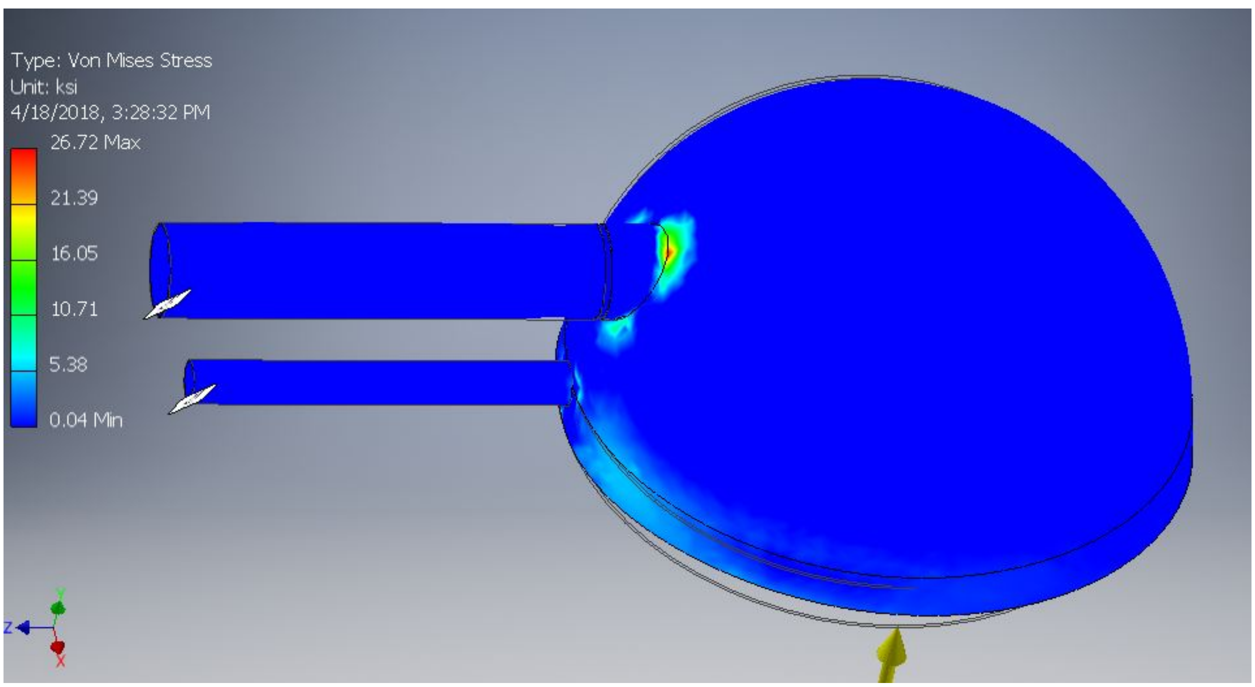


Figure 17: In this figure, the Von Mises stress for the ice cream scoop with a short scraper rod is depicted. While the location of max stress did not move with the addition of the scraper rod, the max stress did decrease. Some stress is also present where the scraper rod meets the bowl.

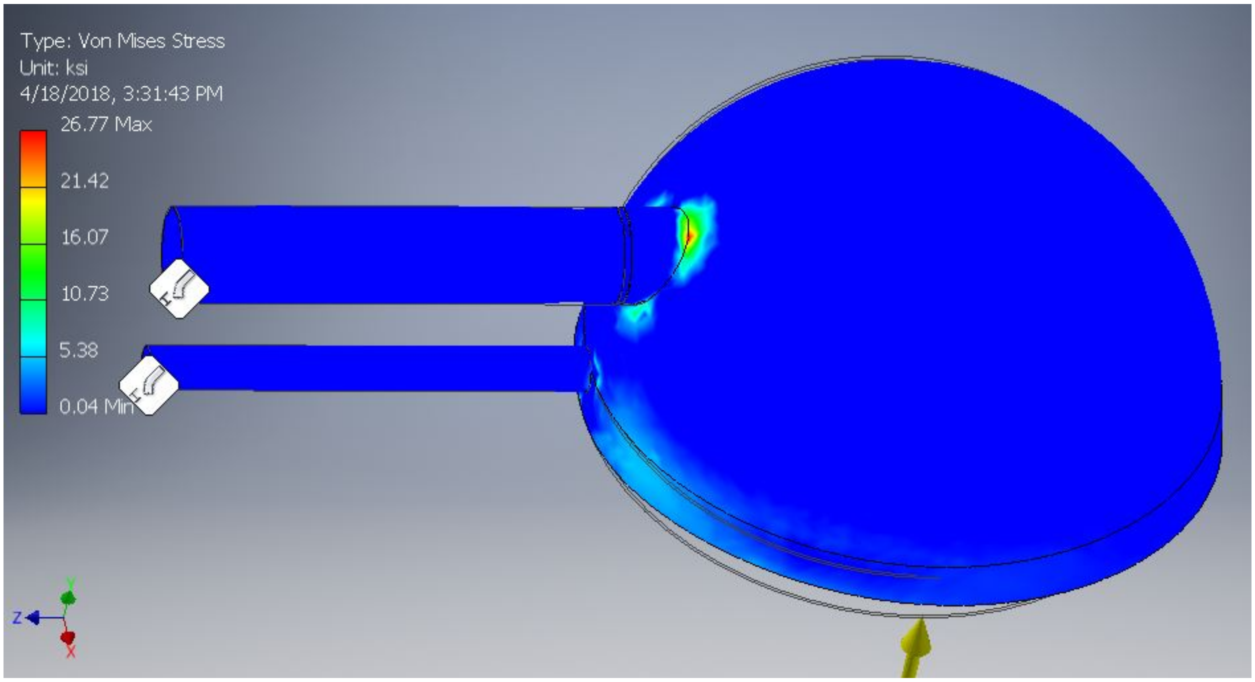

Figure 18: Depicted in this figure is the Von Mises stress of the ice cream scoop with the long scraper rod. Just like the shorter scraper rod, the location of max stress did not change, but it was decreased.