SP18: Tik-Tok Composite Polyurethane Stops

and work on manufacturing the robot foot and shoe

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1 Polyurethane stops

1.1 Design process

The stops are meant to provide a buffer for the robot so that if in case the software fails to stop its limbs from moving past the allowable limits, the stops would hit the robot first instead of two parts of the robot colliding. This is important because if the metal frame of the robot hits another metal frame, there may be damage from the impact. More importantly, we did not want the stops hitting and damaging the springs that are located at the knee and thigh joints.

The main dimensional constraint were the mounting points–the metal frame had a few threaded mounting holes at certain locations, so the stops were designed to be mounted on these holes. The weight constraint was to make it as light as possible, preferably below 30g each. The force that the stops should be able to support was estimated to be around 1000 N, and the stops should deflect around 10-20 mm at the maximum load to absorb enough force.

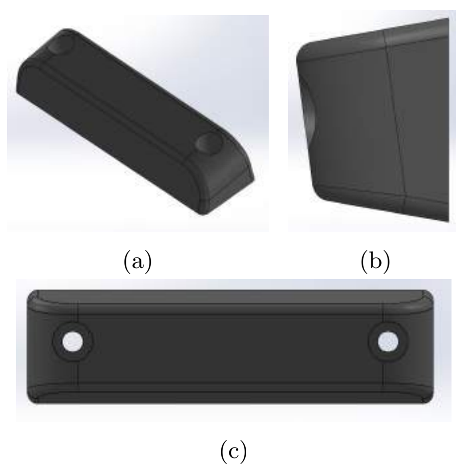


Figure 1: Latest CAD design for stop

Initially, the stops were going to be 3D-printed with Rigid Polyurethane (RPU), Elastomeric Polyurethane (EPU), Flexible Polyurethane (FPU), or a combination thereof using Professor Shepherd's 3D printer. I ran simple force simulations on Solidworks to see how much they would deflect and found that the RPU and FPU are too stiff and the EPU is not stiff enough. I made multiple designs (on Tik-Tok - Mechanical - Stops) using multiple combinations of these polyurethane materials and added geometric variations that changed the structure to be of different patterns so that the infill but the deflections would not meet the criteria, so we moved on to the idea of using two-part polyurethane foam, as shown in Figure 1 and 2. These are made from FlexFoam-it Flexible Polyurethane Foam and PMC 780-Dry Industrial Rubber Compound.

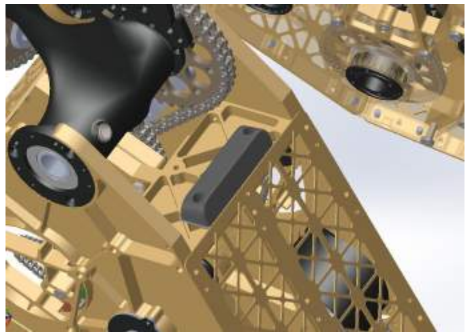
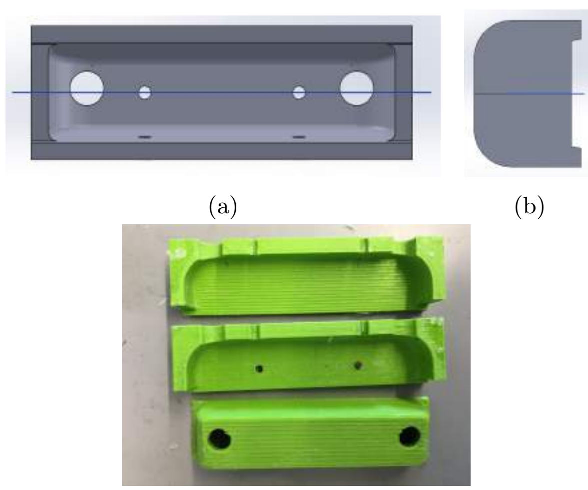


Figure 2: Stop on assembly

1.2 Manufacturing method

To manufacture the stop, I designed a mold, as seen in Figure 3.



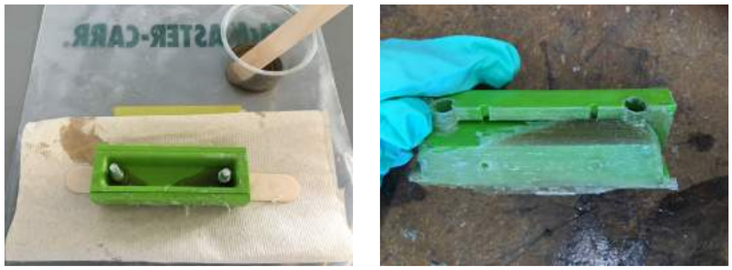
(a) (b)

(c)

Figure 3: Mold

There are two big holes to put an aluminum rod through to model the holes. They have to be removable because when I tried printing the cylindrical extrusions to make the holes on the mold, they broke off while trying to take the piece out of the mold as I explain later in the paper. This also kept happening in the manufacturing of the robot foot, as the extrusions that make the Achilles hole kept breaking off as we pulled the carbon fiber mold off. A removable piece can just be hammered out easily and reused.

The small holes were initially so the rubber could escape while expanding but (1) the rubber didn't really expand much and (2) I flipped the mold over from its initial use case, so the small holes should not be there. The mold is in two pieces to make it easy to pry apart with a flat head screwdriver.



(a) (b)

Figure 4: Process 1

As Figure 4 shows, the first process did not go well. Having the third piece made putting together the mold and putting in the rubber two-part mix difficult. It also did not distribute itself well and I could not fix it because I could not see it. So I took off the third piece of the mold and did a second trial as in Figure 5

(a) (b)

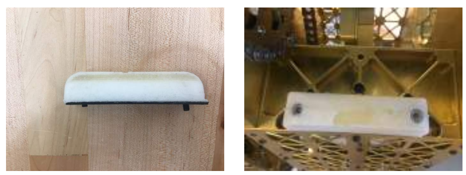
(c)

Figure 5: Process 1

As I refined the process and got closer to the right ratio and amount of two-part mix used, the process also got cleaner, as shown by the difference between the messy Figure 5b and cleaner 5c.

1.3 Results and testing

I did not record the amount of foam and rubber I used on my first try. On my second, I used 6g total of rubber 2-part mix and 17g total of foam 2-part mix. This ended up having a rubber layer that is too thin, among other issues such as too much foam leaking, so I changed the ratio in the third try to 14g rubber and 5g foam. I was not able to test the third iteration, so I do not know whether to put more or less rubber in the next iteration yet, but just by feel, the third iteration definitely is stiffer than the second. I found that putting foam for around half the volume works almost perfectly, and we used this ratio in the shoe foam and it worked very well there too.



(a) (b)

Figure 6: Iteration 1

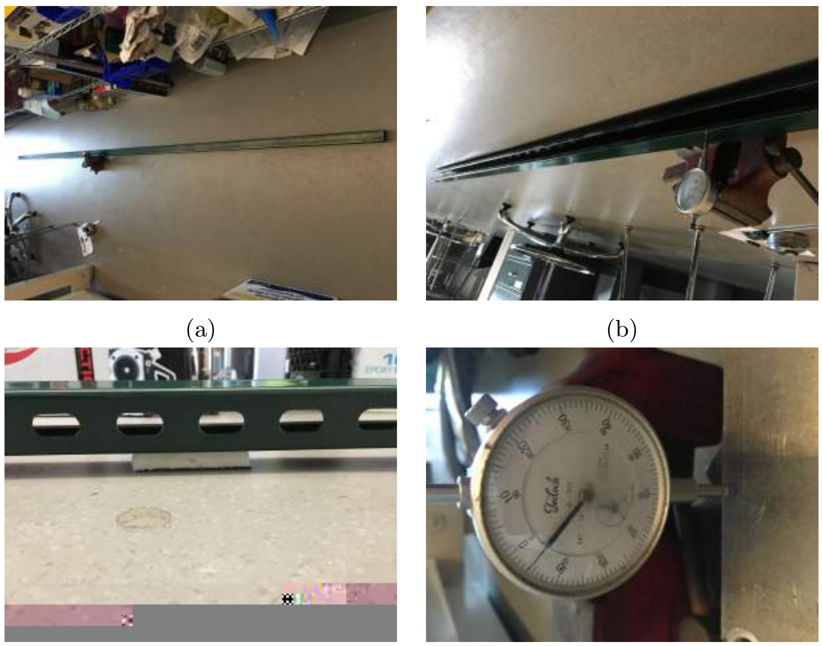
(a) (b)

Figure 7: Iteration 2

(a) (b)

Figure 8: Iteration 3

A quick test suggested by Jason was done to see how much these will deflect. Because I didn't have anyone else to serve as a weight for me, I used a dial indicator to see how much the beam deflected at a certain distance from the "pinned" point of the beam and from the point that applies a force onto the foam. I multiplied the displacement measured by the dial indicator by the ratio of distances to the ”pinned” point and multiplied that displacement by the ratio of 10,000N to my weight. The data obtained is in Table 9, and although there are multiple areas where error could stack up, the values did not seem unreasonable.



(a) (b) (c) (d)

Figure 9: Test

Iteration	Weight	Deflection at 10000N
1 (ratio unknown)	(unknown)	6.5 cm
2 (6g foam, 17g rubber)	14.9g	13.4 cm
3 (5g foam, 14g rubber)	16.8g	(unknown)

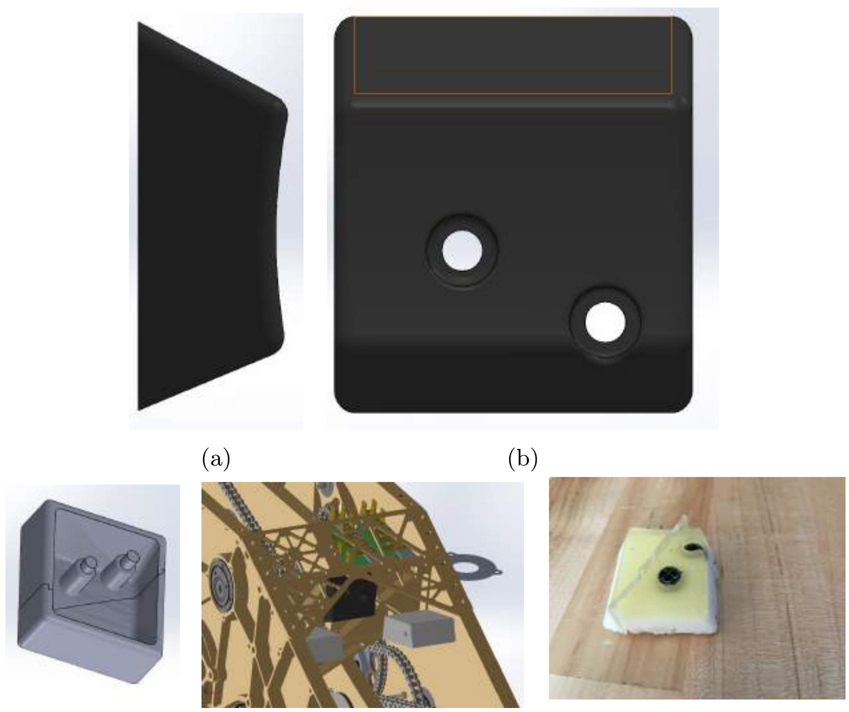
Table 1: Deflection data

1.4 Future work

The foam-rubber ratio should be refined. To reach the goal of 1-2 cm, we need to run a test on the third iteration and then add or remove (more likely add) more rubber from there. The test method should also be refined.

I quickly machined some small aluminum stock to make the extrusions for the hole, but I did not match the measurements to the 3D print, but to the CAD. They need to be re-done to fit the 3D printed parts better.

Work should also be done on other stops. I printed a mold for the stops at the back of the knee but printing the extrusions for the hole as part of the mold is not a good idea, as the extrusions break off with the part being taken out, as shown in Figure 10e.



(a) (b)

(c) (d) (e)

Figure 10: Iteration 3

2 Robot foot and shoe

2.1 Introduction

I helped Brian Lui manufacture multiple of the latest version of the robot feet and shoe and learned a lot about performing carbon fiber layups through this.

2.2 Shoe mold

I made a few changed to the previous mold, the main one being that the curve of the foot changed. Others are detailed below:

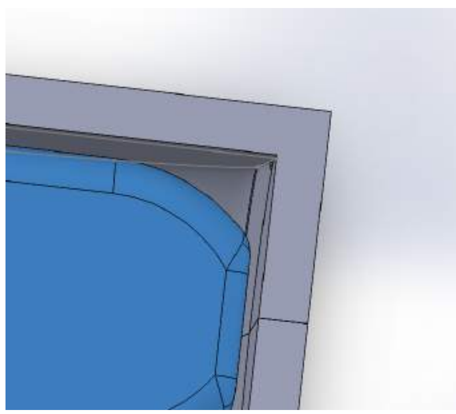


Figure 11: Gap

As shown in 11, there is a 1mm gap between the front of the foot and the mold so that the foam can expand around it.

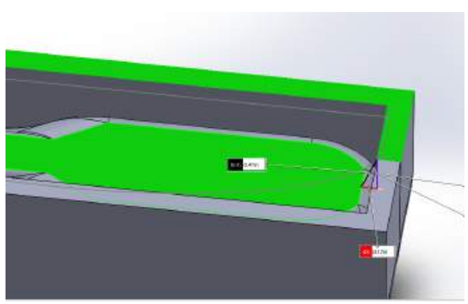


Figure 12: Flush surfaces

As shown in 12, the top of the foot is flush with the top of the shoe mold so that when it moves, we can easily use a plate to push it in place.

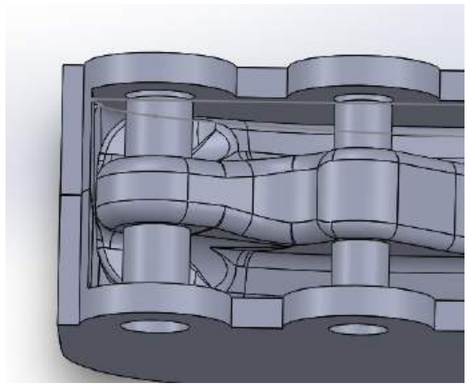


Figure 13: Holes

As shown in 13, I added holes to the original design so that we could keep the foot exactly at the location we want to get a 15 mm foam shoe layer.

3 Acknowledgements

I would like to thank Jason Cortell for offering invaluable suggestions and feedback that was crucial to the movement of this project and who taught me a lot about foams, two-part mixtures, and Solidworks simulations. I would also like to thank Brian Lui for patiently teaching me the carbon fiber layup process, providing feedback on the shoe mold updates, and providing me with a lot of opportunity to do the process myself. I learned so much about carbon fiber,