ME568 Lab 8: Jamming

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I. Fabrication

Describe fabrication and testing setup. During the fabrication process, we followed step-by-step instructions to put together the grasper device. First, we gathered all the materials which included coffee grounds, oat meal, and some mixture of indian tea powder, sugar, and dried cilantro. Then, we filled a party balloon with granulated substance using a funnel. After that, we carefully inserted a small tube into the balloon and secured it with adhesive. We also attached a funnel to the balloon using tape to help with gripping objects later on. Next, we connected a syringe to the grasper with special connectors. Once everything was set up, we tested the grasper by picking up objects of different shapes and weights. We used the syringe to create a vacuum that helped lock the granules in place, allowing us to lift the objects.

Fig. 1. Fabrication of Granular Jamming Structure

Fabrication process for **8b**: First, we cut the paper template along the dotted lines to make pieces for the laminar jamming. Then, we drew an outline on a piece of TPE using one of the paper pieces and layered another TPE on top. After sealing two sides of the TPE to make a pocket, we inserted the paper pieces inside. We sealed the third side of the TPE pocket, leaving the fourth side open, and trimmed any extra TPE. Next, we put a 1/16" tubing into the open side of the TPE pocket and sealed it with adhesive, giving it some time to set. We then put together the syringe by attaching the luer-lock valve and Quick-Turn tube coupler and connected it to the laminar jamming structure. We saw and found that it gets really rigid when we apply vacuum to jam the layers, but it goes back to normal when the pressure comes back.

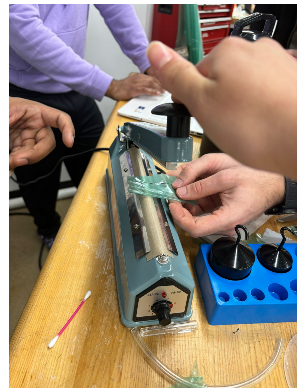

Fig. 2. Fabrication of Lamminar Jamming Structure

Fabrication process for **8c**: The fabrication process for this part of the lab was same as that for the part b of the lab. For the new 2 TPE pouches we used coffee grounds and a mixture of oatmmeal and indian tea granules along with some sugar and dried cilantro.

II. Testing and Analysis

For testing of the Laminar Jamming, we added a 20g weight on all three structures which consisted layers of 10,20 and 30 respectively. We recorded the deflection in length when weight is added. We also recorded the deflection in length when air is pumped out, i.e. when it is jammed. The length of the TPE pouch is 5.5cm, breadth is 2.5cm and height of each layer is 0.1cm.

TABLE I
LAMINAR JAMMING

Layers	Length (cm)	δ Unjammed (cm)	δ Jammed (cm)
10	10.0	3.8	2.9
20	10.0	3.0	0.4
30	10.0	2.2	1.5

For finding the Elastic Modulus E, we have formula

$$\delta = \frac{Fb^3}{3EI}$$

where F is the force applied, b is the breadth of the TPE pouch, E is the Elastic Modulus, and I is the moment of inertia. To calculate the inertia, we have formula:

$$I_{\text{preslip}} = \frac{bN^3h^3}{12}$$

$$I_{\text{unjammed}} = \frac{bNh^3}{12}$$

where b is the width, N is the number of layers, and h is the height of each layer.

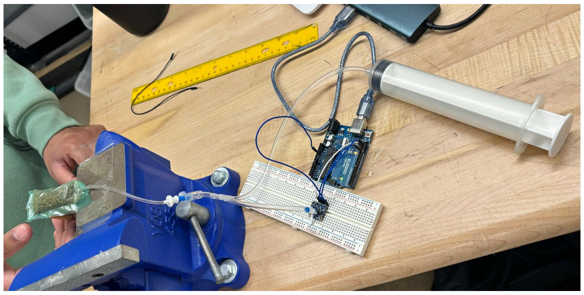

Fig. 3. Testing of Granular Jamming Structure

Here the Force = Mass * Acceleration, the weight we applied is 20g and the acceleration is $9.8\,\mathrm{m/s^2}$. Therefore converting force CGS system, would give force = 19600 Dynes. The breadth of the pouches is 2.5 cm. The height of the layers is 0.1 cm.

TABLE II
ELASTIC MODULUS OF LAMINAR JAMMING

Layers	I_{preslip}	I_{unjammed}	E_{unjammed}	E_{jammed}
10	0.208	0.002	12894736.84	168965.5172
20	1.666	0.0041	8166666.6	153125
30	5.625	0.00625	7424242.42	12098.76

For part 8C, we did the same experimental setup with 20g weight for two more TPE pouches filled with granular materials: one is Ground Coffee and other with Oatmeal. The length of the TPE pouch is 5.5 cm, breadth is 2.5cm and height is 0.6 cm

TABLE III
GRANULAR JAMMING

Materials	**Length(cm)**	**δ Unjammed**	**δ Jammed**
Coffee	8.4	1.9	0.3
Oatmeal	8.6	2.5	0.2

For finding elastic modulus of granular jamming (coffee and oatmeal), we have The breadth of the pouches is 2.5 cm. The height of the layers is 0.6 cm. I_{preslip}, I_{unjammed} and δ(Deflection).

TABLE IV
ELASTIC MODULUS OF GRANULAR JAMMING

Layers	I_{preslip}	I_{unjammed}	E_{unjammed}	E_{jammed}
Coffee	5625	2.25	23879.1423	60.49382716
Oatmeal	5625	2.25	18148.14815	90.74074074

III. DISCUSSION

Plot the change in the elastic modulus of the beams (layer jamming and granular jamming) as a function of the volume of the pouch or the pressure inside the pouch.

For testing of the pressure inside the pouch, we set up the Arduino circuit, using the MPRLS sensor for pressure detection.

Change in elastic modulus vs Pressure change inside the pouches for Laminar Jamming: To calculate the pressure change inside the TPE pouches, we added a 20g weight on the pouch, and recorded the pressure inside when it was unjammed and jammed.

TABLE V
CHANGE IN ELASTIC MODULUS AND CHANGE IN PRESSURE INSIDE POUCH FOR LAMINAR JAMMING

Layers	E_{Unjammed}	E_{Jammed}	P_{Unjammed}	P_{Jammed}
10	12894736.84	168965.5172	103.54	61.24
20	8166666.667	153125	103.67	83.55
30	7424242.424	12098.76543	103.89	93.41

A plot of change in Elastic Modulus vs pressure change inside pouch for Laminar Jamming is shown below:

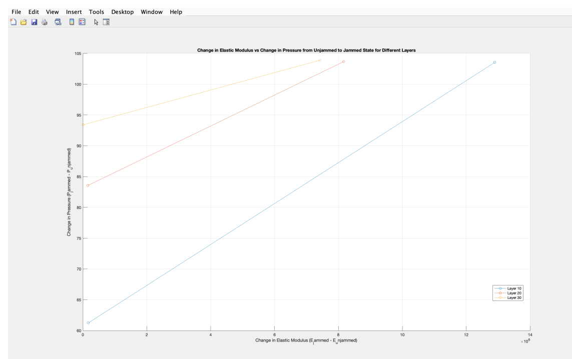

Fig. 4. Change in Elastic Modulus and Change in Pressure inside pouch for Laminar Jamming

TABLE VI
CHANGE IN ELASTIC MODULUS VS PRESSURE CHANGE GRANULAR JAMMING

Material	E_{Unjammed}	E_{Jammed}	P_{Unjammed}	P_{Jammed}
Coffee	1193957.115	7561728.395	108.04	61.44
Oatmeal	907407.4074	11342592.59	104.69	50.53

Plot of change in Elastic Modulus vs pressure change inside pouch for Granular Jamming is:

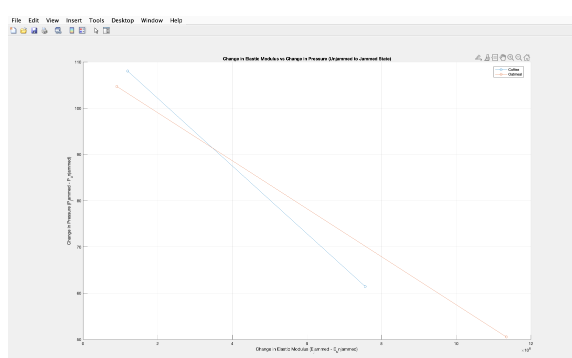

Fig. 5. Change in Elastic Modulus and Change in Pressure inside pouch for Granular Jamming

How does the strength/stiffness of jammed structures change compared to unjammed structures? Compare laminar and granular jamming and discuss what are the strengths and limitations of each approach.

Jamming the structures had a significant impact on their stiffness. In both cases, layered and granular, the stiffness of the structures increased significantly when jammed. In the layered structures, we also observed a change in the plasticity of the structure. IF the jammed structure was bent enough to cause the layers to slip, once force was no longer applied the structure would remain in a different shape corresponding to the new positions of the layers. This allowed us to adjust its position by bending it into shape while a vacuum was applied. When unjammed, the layers are always free to reset into their original place, so the structure had lower plasticity. On the other hand, the granular materials exhibited no significant change in plasticity. They did however, achieve much higher strength than the layered structures. As they do not have layers to slip when too much deflection occurs, the granular material pouches were able to retain their shape with larger weights applied to them. However, it was noticed that when unjammed, the granular structures had trouble keeping a roughly rectangular shape, and often had to be manually formed back into shape for testing. Overall the results seem to indicate that granular jammed structures are capable of achieving higher strength, but struggle to hold their shape when unjammed. Layered jammed structures achieved less stiffening (although it was still significant) but exhibited an additional change in plasticity, which can prove useful in applications where it is important to maintain manual deformation, with the ability to quickly reset shape (via unjamming the layers).

How does the number of layers affect the stiffness of laminar jamming structure?

After doing tests on several layered structures with different layer numbers, we observed that in general the higher the amount of layers, the stiffer the structure becomes when jammed. From a theoretical point of view this makes sense, as when unjammed, all the layers slide over each other, providing very little additional strength. But when jammed, all the layers act as a single beam, whose cross sectional area is proportional to the number of layers. Therefore a larger amount of layers should yield a stiffer structure when jammed (assuming no layer slip). However, we did measure the 30-layer structure as being less stiff than the 20-layer structure. This, we think, was due to errors in construction of the 30-layer structure, which resulted in air leaks and sloppy vacuum, leading to the jamming being less effective, which would decrease the stiffness of the jammed structure. We expect that redoing the tests with a new properly-built 30-layer pouch would yield higher stiffness than the 20-layer pouch.

Discuss the effect of the different particles on granular jamming structure. Consider the influence of the particle size and shape on the packing fraction.

In the granular jamming structures, how effective the jamming is at increasing stiffness depends greatly on the size and shape of the granules, as well as which granules are mixed together. In our tests, the structures with larger, more irregular granules (like coffee grounds) tend to achieve smaller packing fractions, while smaller particles with more regular shapes (like rice or sugar) achieved much greater packing fractions. Interestingly enough, some granular materials (oatmeal in our case) exhibited an interesting property. When actuated or otherwise disturbed, the dry oatmeal created a significant amount of dust, which after jamming the structure, filled in pockets of air within the larger oatmeal pieces, achieving much greater packing ratio. Notably as well, due to the flat, disk-like shape of the oatmeal granules, we observed a similar plasticity effect as that of the layer jamming structures, as the oatmeal disks would slide over each other. This leads us to conclude that granular jamming structures can be constructed to have very complex behaviours simply by filling them with mixtures of different granules with different sizes and shapes. And additional effects like plasticity changes can be achieved. Furthermore, the data from another group (who used rice) showed a similar behaviour to that of our coffee grounds pouch, with the main difference being that the change in stiffness was slightly smaller. This can be explained by the slightly smaller size of the granules, and the fact that their more regular and smooth shape allows them to slide over each other better than the coffee grounds, which catch on one another with their sharp edges.

IV. Appendix

Fabrication pictures:

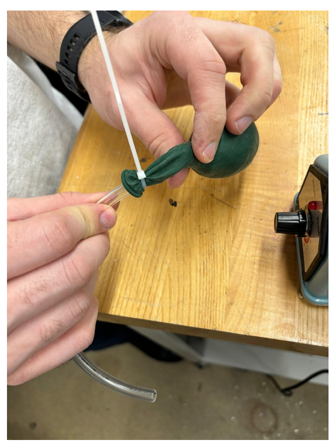

Fig. 6. Fabrication of Granular Jamming Structure

Fig. 7. Fabrication of Granular Jamming Structure

Fig. 8. Fabrication of Lamminar Jamming Structure