ME568 Lab 4: TPE Ballon Actuators

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I. Fabrication

In this lab we fabricated two different finger actuators employing TPE balloons and pneumatic actuation. Each actuator has a different design and aims to demonstrate the use if inflatable TPE balloons in constructing soft robot actuators.

In crafting the first actuator, our group employed a methodical approach. We created a tower-shaped paper outline, inserted it into the material, and applied hot pressing to generate the desired cavities. The design principle guiding these cavities was systematic: The cavity closest to the tube had the smallest opening diameter and the remaining cavities featured increasing opening diameters in such a way to create measurable difference between every pair of consecutive cavities.

When making the second actuator, we first constructed a thin rectangular balloon by folding a piece of TPE sheet over a cardboard template, fusing the seam to make a cylinder, and finally fusing the ends of the cylinder together. A tube was then inserted into a puncture in the cylinder at one end and sealed with Teflon tape. Kinks were introduced artificially into the balloon by making small folds and taping them together. Secondly, a non-strech sleeve was made using heat-weldable fabric with the same process as the rectangular TPE balloon, but only fusing one end rather than both. The balloon was inserted into the sleeve, and cuts made to one side of the sleeve at the same height as the kinks in the balloon inside it. When pressurized, the balloon inflates. The side with no kinks stretches fully, but the side with kinks cannot, creating firm bends in the balloons with in turn bend the external sleeve.

II. Discussion

A. TPE Actuator and its Mathematical Modeling

Unlike the silicone actuators from the previous lab, which actuate by stretching when pressurized, the TPE used in this lab has very little stretch. Because of this, the TPE actuators inflate, rather than stretch. The fingers we made are constructed to be loose, and when pneumatically actuated, they inflate and grow in volume as they fill with air. Once enough air is in the actuators to fill their entire volume, any additional air will only increase the internal pressure, not the volume, as the balloon does not stretch any further. As the balloon's pressure increases, there is a significant increase in the force output. This will affect the mathematical modelling, as we now assume that the balloon only stretches a little, so we can model them as constant volume once inflated, whereas modeling the silicone elastomers mainly focuses on describing their elastic behavior, i.e., their stress-strain relationship.

B. Stretching Of The Thermoplastic Elastomer

Depending on the specific TPE used, the material can return to its original state from a moderately strained state after the removal of stress. Without this elasticity, the material would yield and gradually expand under the actuating pressure, which would be unpredictable and would prohibit the design of any kind of robust control. Care must be taken to not expect the material to withstand too much stress or strain under normal operating conditions in order to successfully design and control TPE actuators.

C. Pressure Of The Thermoplastic Elastomer

The TPE actuator with multiple cavities fully actuated with a 19.8 kPa pressure difference, and the shorter, single-cavity actuator with an 11.81 kPa difference. These pressure ranges are much less than those required for the elastomeric actuators (tested in lab 3) for similar strokes. This is as expected, since actuation by inflation is characterized by a large change in volume, and actuation in elastomers primarily by the material's elastic response to applied pressure. The shorter actuator's stroke was difficult to quantify since the end curled much quicker than the rest of the length (diverging from the expected constant curvature behavior).

D. Thermoplastic Elastomers Vs. Silicone Elastomers

For use in the construction of soft robots, TPE has a few advantages over silicone. While its operational temperature range is by no means as wide as that of silicone (The range of TPE is approximately -30 to 250°F; whereas the range for silicone is arround -150 to 480°F [1]) TPE is more resistant to mechanical abrasion and tearing, and can handle contact with a wider range of solvents. This can make it a better material choice in components that will be exposed to significant mechanical wear, but will not need to operate in harsh temperatures. It can also offer higher softness and flexibility than silicone lending itself well for example to robots that must come into contact with more delicate items.

When it comes to manufacturing, silicone is typically expensive. The component chemicals are complex and difficult to manufacture, and parts made out of it involve more complicated processes as they need to be cast and cured in precise ways. TPE, on the other hand, can be easily melted and reformed with negligible loss of material properties, allowing many different fabrication processes such as pressing, injection molding or extrusion to be applied easily at low cost. Together with the fact that the TPE itself is typically simple simple to manufacture, requiring no reinforcing additives or stabilizers, the cost and complexity of manufacturing is usually much lower with TPE than with silicone. This makes it a desirable material in low-cost mass-production applications.

III. Appendix

The images below show the finished actuators:

Fig. 1. Complete Cavity Actuator

Fig. 2. Complete Sleeve Actuator

References

[1] J. Hoffman, "Tpe vs. silicone: Which is better?" https://www.timcorubber.com/blog/archive/tpe-vs-silicone-which-is-better/, Custom Rubber Products & Parts Supplier, 2022.