Observing Interfacial Creases in PDMS

Anusuya Arjavalingam, Xudong Liang, and Shengqiang Cai

Department of Mechanical and Aerospace Engineering, University of California, San Diego, 9500 Gilman Drive, La Jolla, California

Objective

To experimentally prove the existence of the theoretically simulated creation of an interfacial crease that is formed in Polydimethylsiloxane (PDMS) when compressed.

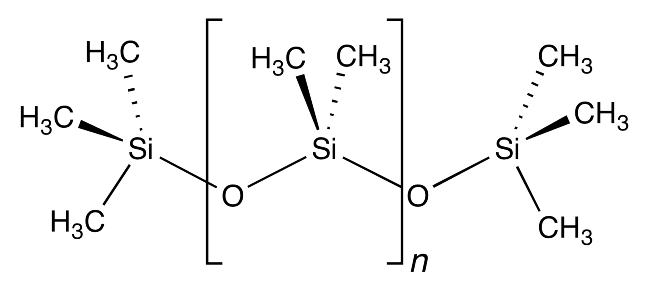
Background

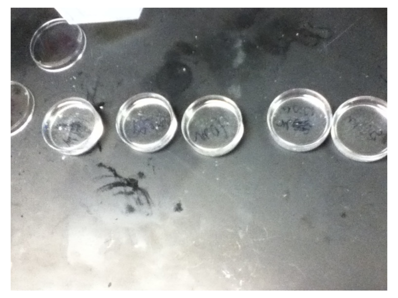
Soft materials are abundantly present in biological systems and in daily life. They deform greatly in response to stimulus, a characteristic that provides many useful functions. Despite these facts, research on soft materials is still at a nascent stage. Our overarching goal is to better understand the properties of these materials.

One relatively unstudied property is called the interfacial crease. This structural formation present in two bonded layers of material. Bonded materials are pervasive, found in composite materials, geological strata, electronic devices, biological tissues, and soft actuators. It is common for stresses to arise from thermal differences, chemical reaction, growth, swelling, or mechanical pre-strains. These may cause buckling instabilities, leading to the weakening of the interfacial bond between the two layers. Additionally, the interface might have defections caused by scratches or impurities. The interface would slightly separate at the site of the defection.

When the interfacial bond is at a certain strength (weak enough to allow for tears and strong enough to keep the material intact under stress) and when there is a defection on the interface, the scenario for interfacial crease formation is born. When the material is compressed at a perpendicular direction to the interface, a particular shape is formed to maintain the lowest possible energy in the material. The interface slightly separates and creates a diamond shaped opening. The formation of interfacial crease causing by a prior separation of the interface has not yet been studied experimentally; it has only been simulated with computer programs. It has shown to be effected by the existence of a defection, strength of the interfacial bond, and the percentage of compression. It is not effected by the stiffness of the material. Our goal was to create the conditions under which the crease will form and validate its existence using the widely prevalent and purposive material, polydimethylsiloxane.

PDMS: Properties and Preparation





Polydimethylsiloxane (PDMS) belongs to a group of polymeric organosilicon compounds that are commonly referred to as silicones. PDMS is the most widely used silicon-based organic polymer and is particularly known for its unusual rheological (or flow) properties. It is viscoelastic, meaning that during long flow times or under high temperatures, it acts like a viscous liquid, and under short flow times, or under low temperatures, it acts like an elastic solid.

PDMS is translucent, and, in general, inert, non-toxic, and non-flammable. It is also biocompatible, meaning it does not harm living tissue. Solid PDMS samples have external hydrophobic surfaces. PDMS's applications include use in cosmetics, contact lenses, medical devices, caulking, lubricating oils,and ad heat-resistant tiles, and as an anti-foaming agent in food and medicine. It is used to for flow delivery in microfluidic chips. Recently, it has been developed as a base for artificial skin. The unique traits and frequent usage of this material make it vital to fully understand its properties.

A standard procedure was used to create the PDMS.

1. First weigh out a portion of the silicon base.
2. Weigh and add enough curing agent so that there is a ratio of 20 parts base to one part agent.
3. Stir vigorously for 5 minutes.
4. Fill a Petri dish halfway with this mixture.
5. Let mixture sit until air bubbles disappear.
6. Put the dish in the oven and let PDMS cross-link.
7. Take dish out of the oven.
8. Add any defections to the first layer, which serve to prompt interfacial crease formation (e.g. by scratching or adding a piece of string.
9. Repeat steps 1-3.
10. Fill the rest of the Petri dish with the new batch of PDMS.
11. Place back in the oven and let 2nd layer cross-link.

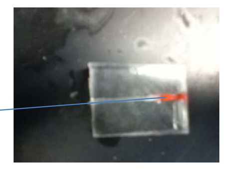
Optimizing Sample Preparation

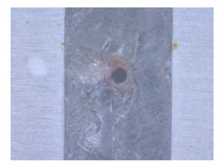
Cook time: The 1st layer of PDMS was baked in the oven for various times to uncover the minimum amount of time that was required to crosslink the first layer. 90 minutes was found to be the minimum time needed at 50 °C .

30 min	60 min	90 min	120 min	150 min
No visible interface	No visible interface	Visible interface	Visible interface	Visible interface

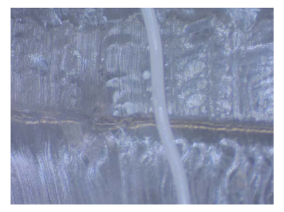
Creating Deformations: Various materials were used to create deformations. First, a glass needle was placed on the first layer before the second layer of PDMS was poured on. The needle was too heavy and sunk into the first layer. Ultimately, a plastic string was used. The defection was still asymmetrical along the interface, as the string rested on top of the first layer. However, the hole was still at a location where it could form a crease under compression.

(Red pen ink)





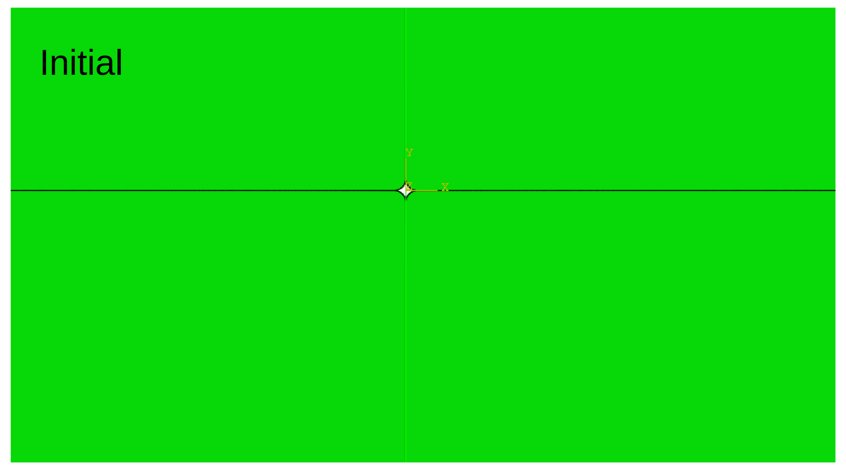
Varying Stiffness: The stiffness of the PDMS can controlled by the amount of curing agent that is added. More curing agent creates a stiffer material. Most samples where made of two layers with a 20:1 ratio of base to agent. However, some samples had one layer with a 30:1 ratio of base to agent, making one layer softer. The stickiness of the softer layer seemed to prevent defections from fully forming, so no interfacial crease formed. Large surface creases formed on the softer half when these samples were compressed.

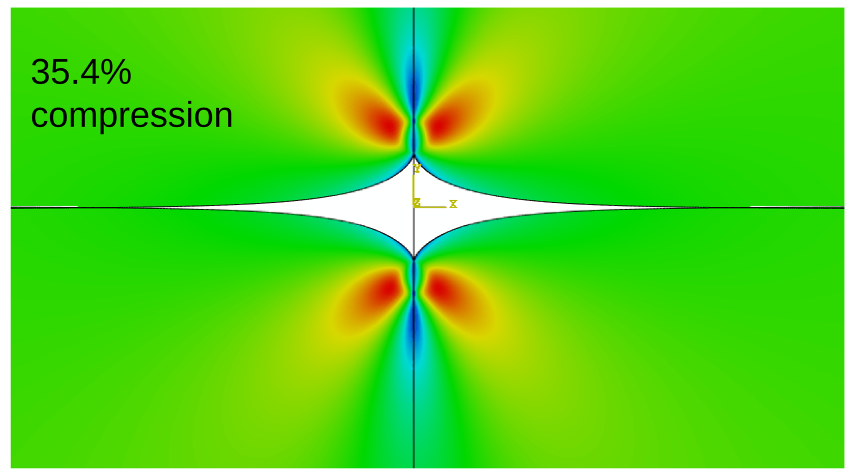


Observing Interfacial Crease

Computer Simulation

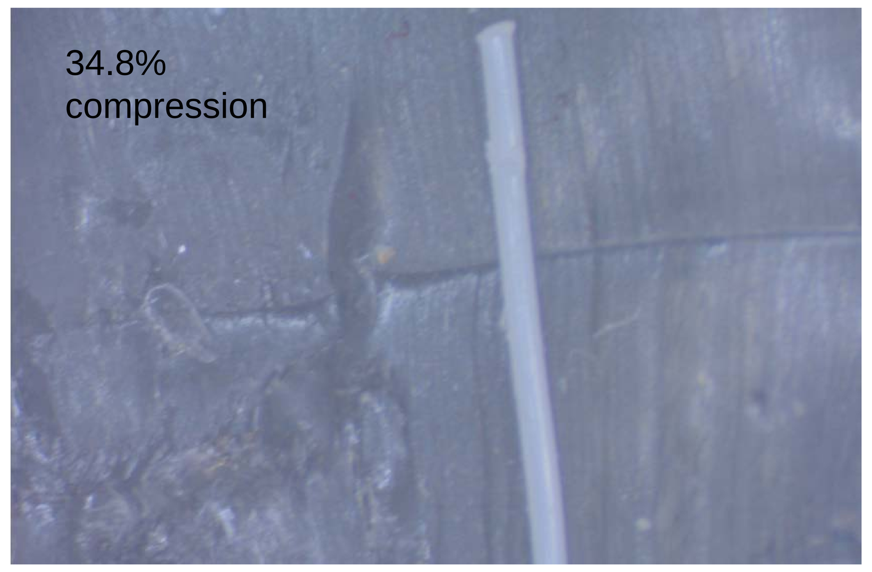
Abaqus, a software suite for finite element analysis and computer-aided engineering was used to simulate the interfacial crease formation.





Experimental Results

Plastic string, diameter= .25 mm



Comparison of Theoretical and Experimental Results

Our results showed a separation of the interface. However, the inward crease was larger and asymmetrical. There were three main differences between the simulation and our experimental set-up:

1. In the simulation, the defection is distributed symmetrically along the interface. In experiments, there is some error in aligning the defection, making the crease grow differently on the two sides.
2. In the simulation we assume the material is plain strain, meaning the direction perpendicular to the compression has zero strain. However, in the experiment, we could not avoid strain in this direction.
3. In the simulation, we assume a uniform compression along the interface, but in experiment, due to the limit of the compression mechanism, the compression is not uniformly applied to the material.

CONCLUSIONS AND FUTURE DIRECTIONS

Accomplishments:

- **We created conditions under which an interfacial crease can form by using a specific stiffness of PDMS and plastic string to create a defection.**
- **We experimentally validated the presence of an interfacial crease in PDMS at the site of a defection.**

Future Goals:

- Use a compression machine that can more evenly distribute force along the sides of the material.
- Find a method for varying and quantitatively measuring the adhesiveness of the interfacial bond to observe how bond strength effects crease formation.
- Observe interfacial creases in other materials.

References

Jin, Lihua, et al. "Creases on the interface between two soft materials." *Soft matter* 10.2 (2014): 303-311.