Thin Membrane Mechanical Characterization System

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Abstract
Mechanical properties of hydrogels are important in the design and manufacture of contact lenses and other thin membranes. This project examines two different experimental setups for examining the properties of a thin membrane. One configuration is an inflation test and the other is a delamination test. In the inflation test, the membrane is clamped between two plates and pressure is applied to the underside. In the delamination test, the membrane is simply placed onto a flat plate with a small hole and pressure is applied to the underside. In order to design a fixture capable of performing both tests, various factors were taken into consideration, including where to measure the pressure being applied, how to gradually apply pressure to the sample in a controlled manner, and how to best view the sample during testing. A fixture was designed with interchangeable test plates in order to accommodate both test configurations and satisfy all design requirements. Pressure is applied using a syringe pump and critical data is collected continuously using LabVIEW along with images of the sample at different points during the test. An interferometry system is used to analyze sample deflection. A prototype of the proposed fixture has been built and validation testing is in progress to determine if this test setup accurately matches theoretical models.
The Need for Project

A fixture to experimentally determine the mechanical properties of fragile thin membranes is needed to allow for improved contact lens designs. Currently, testing to determine material properties, such as elastic modulus and Poisson’s ratio, is typically done on dog-bone shaped samples using standard universal testing machines. This method is not viable for use on fragile thin membrane samples. With the design of a more delicate fixture, researchers would be able to verify theoretical models for thin membrane behavior and designers of products made from thin membranes would benefit greatly. For example, designers of contact lenses would be able to develop safer and more comfortable lenses with a better understanding of the mechanical properties of thin hydrogel materials. Presently, there are no commercially available products to perform these tests by applying pressure to the sample.

The Design Project Objectives and Requirements

The objective is to design a fixture capable of performing two separate tests on a small, thin membrane in order to verify theoretical models for its behavior.

Design Objectives

The goal of this project is to develop a test fixture that will be capable of providing data to verify theoretical models for thin membrane behavior. The fixture should be capable of performing two tests involving the application of pressure to the underside of a membrane. One will yield data in order to determine the adhesion properties of the material (Rep. 2.1). The other test will gather data to aid in the determination of the elastic modulus of the material under test (Rep 2.2). Performing these tests is challenging because the samples are approximately the size of a contact lens.

Design Requirements

One fixture needs to be designed that is capable of performing both tests mentioned above with a sample as small as 10 mm in diameter. The fixture also needs to be able to perform both tests in air and an aqueous solution. The pressure under the sample as well as sample deflection and delamination radius need to be accurately measured during the tests. The sample must also be able to be imaged during the test. Finally, the fixture should be capable of being cleaned and sanitized after each test.

Design Concepts Considered

Several options were considered for the tank design, clamp

Tank Designs

Several alternative tank designs were considered, primarily
design, and pressure/volume control system. The most promising option for each component was chosen to compose the final design. Focusing on options for incorporating the pressure/volume control system (Rep. 4.1). One of the initial ideas was to have an elevated tank with a moveable bottom plate to act as a large piston. Another alternative was to have a cylinder machined into the side of the tank to accommodate a piston. These options did not provide for much flexibility or precision, so it was determined that a port to attach an external control system would be the best option.

**Pressure/Volume Control Systems**

Numerous options were examined for the pressure/volume control system (Rep. 6.4.1). One of the early choices was a piston-cylinder assembly controlled by a micrometer, but it was decided that an automated system would be more accurate. Options for driving the piston were a linear actuator, stepper motor, and syringe pump. They were all similarly priced, but the syringe pump provided the greatest accuracy and ease of implementation for its cost.

**Clamp Designs**

Different clamp designs were examined to try to optimize the view of the clamped sample (Rep. 5.2.1). The ability to get an unobstructed view of the fragile sample, while securely holding it without causing damage, was one of the most critical aspects of the fixture design. Initial concepts involved clamping the sample between two flat plates. This method proved unacceptable due to the expected deflections being only around 1 mm. With such small deflections, the top plate obstructed the view of the sample. Attempts were made to design a notch in the top plate to improve visibility, but this was still not ideal. Eventually, a clamp similar to the chosen cylinder design was found in a published research paper and adapted for this application.

**Recommended Design Concept**

The recommended design utilizes a multi-segment tank with interchangeable test plates to achieve the design objectives. A syringe pump is used to apply pressure, deflection is determined using an interferometry system, and critical data is recorded.

**Design Description**

The fixture consists of a two-segment tank, pictured to the left on the next page, which is capable of accepting a variety of test plates in order to adapt for different test configurations. One of the test plates is a clamp, also pictured to the left on the next page, which uses two clear acrylic cylinders to clamp the sample between mating beveled surfaces. This design allows for an unobstructed view of the sample. The other test plate is a flat plate with a 1 mm hole in the center.
through a LabVIEW interface through which pressure is applied to delaminate the sample from the substrate. The upper tank segment is made of acrylic and has a glass window to allow for a clear view into the sample. The lower tank segment has a 20 mm hole in the top, which lines up with the test plates to apply pressure to the sample. There are also ports on two sides of the base of the tank. One port is for the pressure transducer and the other is to attach the pressure application system.

A syringe pump is used to control the pressure/volume under the sample. It is connected to the tank via vinyl tubing between dedicated fittings. This pump allows for changes to be made accurately and slowly with an automated device. As the sample deforms under the applied pressure, it is imaged through the glass window using a mounted camera and lens system capable of up to 200x magnification.

The camera is tied into a computer along with a LabVIEW interface to monitor the test duration, pressure, and amount of fluid dispensed during the test.

The tank also has a recessed window on the bottom face that is in line with the sample so that it can be used with an interferometry system that is being developed independently of this project (Rep. 8.1). This interferometry system will be used to determine the sample deflection during the test. This overall system allows for a clear view of the sample as well as the ability to record important data for experimentally verifying the theoretical models that were developed.

### Analytical Investigations

Preliminary calculations were done to determine the expected values of the critical parameters for each test. For the clamped inflation test, the most important parameter was the pressure applied to the sample. Initial calculations showed an expected maximum pressure of approximately 0.04 psi (Rep. 6.2). This value was the determining factor in the pressure transducer selection.

The critical parameter for the delamination test configuration was the volume of fluid under the sample. Estimates showed that the maximum expected volume would be around 260 mm$^3$ (Rep. 6.3). This estimate was the driving factor in the selection of a pressure/volume control mechanism.

### Experimental Investigations

Some experiments have been done to examine sample visibility
with the proposed test setup and have shown good results. At this point, preliminary testing has been done to evaluate seals and pumping capability, with promising results. The remaining validation testing is expected to be completed in the coming weeks.

**Key Advantages of Recommended Concept**

As designed, the primary advantages of the fixture are the clear view to the sample inside the tank as well as the multiple tank segments, which make sanitation between tests easy. Another major advantage is the ease of control of the fluid flow into the tank. A flow rate can be set and accurately applied without human error. The LabVIEW interface also provides a simple means for gathering data.

**Financial Issues**

The total cost of the initial prototype was approximately $1220, excluding machining labor costs and the interferometry system. While this fixture was designed for research purposes, contact lens companies have shown interest in acquiring this type of system to monitor material properties on the manufacturing line. The cost of the materials for the prototype was approximately $1220 (Rep. 10). This amount does not include labor costs of machining, as it was all done in the Northeastern University machine shop, or the cost of the interferometry system, which was developed separately from the fixture design. The total cost to build the entire system is estimated to be around $2000.

**Recommended Improvements**

Work to improve the sample visibility and imaging would allow for improved accuracy of the data provided by this fixture. The laser interferometry system mentioned above is in development by graduate students in Professor Wan’s research group. The completion of this system will allow for accurate measurement of the deformed sample profile.

Methods of improving sample visibility and imaging should be further examined. Alternative clamp designs were discussed and could be examined to try to optimize sample visibility. Additionally, due to budget and time constraints, an already available camera and lens system had to be used. Future investigations could look into a camera specifically for this test to try to get a better image resolution. An improved method of viewing and/or imaging the sample would provide an improvement in the quality of the results from this fixture.