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Joshua Bunch

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Mechanical Characterization of Spherical Hydrogels: Contact Diameter Measurement

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Joshua Bunch [b], Kai-tak Wan [a,b]

[a] *Department of Mechanical Engineering, University of Missouri-Rolla*
[b] *Department of Chemical and Biological Engineering, University of Missouri-Rolla*

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Abstract

In an effort to develop new ophthalmic treatments revolving around the ocular lens, the mechanical characteristics of natural ocular lenses and synthetic models must be determined and compared. One mechanical characteristic that is necessary when making comparisons is the variation of contact circle diameter or contact area with varying strains. A method was used in this experiment to measure the varying contact circle diameter of spherical hydrogels at strains up to 15%. This method could be used to estimate the varying contact diameter of other similar materials such as natural ocular lenses if the precision of the method is improved. The elastic modulus of the spherical hydrogels was also calculated. Averaging over all strains, the elastic modulus was found to be 3.459 kPa with a standard deviation of 1.263 kPa. If the lower strains (1% and 2% strains) were ignored, the elastic modulus was calculated to be 4.071 kPa with a standard deviation of .676 kPa.

Introduction

Hydrogels have the potential to be used in the development of ophthalmic treatment options for conditions such as presbyopia[1] and cataracts. Presbyopia is a condition that is age-related and characterized by the loss of power to focus on close objects.[2] Cataracts is a condition in which the lens becomes cloudy thus impairing one's vision. The elderly are the most likely to develop cataracts.[3] In order to determine there ability to simulate the natural ocular lens, hydrogels and lenses must be mechanically characterized and compared with one another.

The experimental goal was to determine a method for measuring the changing contact circle diameter of a spherical hydrogel under varying strains. To measure the varying contact circle diameter, pictures were taken at varying strains. The pictures were analyzed, and the contact circle diameter data was correlated with the varying strains. The elastic modulus of the spherical hydrogels was also determined based on a model outlined in previous literature.

Materials

Spherical hydrogels were obtained from Washington University in St. Louis, Missouri. The hydrogels were made through the copolymerization of acrylamide and the use of a disulfide bisacrylate cross-linker. The method for developing the polymeric hydrogels is outlined in previous literature.[1]

All quasistatic loading tests were conducted using a TA.XTPlus Texture Analyser from Texture Technologies Corporation and the associated software, Texture Exponent 32. A one inch cylindrical probe was used during the tests. The machine was calibrated for force and height prior to running the tests.

The spherical hydrogels were submersed in distilled water at room temperature during testing to prevent the hydrogels from becoming dehydrated. The water was held in a transparent container in which a small plexiglass platform was present. The hydrogels were placed on the platform. The water level was kept significantly above the top of the spherical hydrogel. Figure 1 shows the testing container, platform, and probe.

Pictures were taken with an 8.0 megapixel Konica Minolta DiMAGE A200 camera. The camera was stabilized using a stand with telescoping tubes. The pictures used to determine the contact area were taken remotely to minimize shaking and subsequent error. The pictures were analyzed using ImageJ, a software program freely distributed by the National Institutes of Health.

Methods

Prior to beginning the quasistatic testing on the spherical hydrogels, the height of the samples had to be determined. This was accomplished by running a quasistatic test in water without the sample and then with the sample in water. The sample was only slightly loaded in this height determination test. The load versus displacement plots for the runs were then compared and the height was determined based on the point where the two graphs began to significantly deviate from one another. The hydrogel height was taken to be 0% strain even though there was some compression due to the weight of the hydrogel and water surrounding the hydrogel. During all tests, the probe was always brought down from a set height to the starting height, which remained constant for all replicates. This was done to minimize any variation from the water's meniscus like action on the probe.

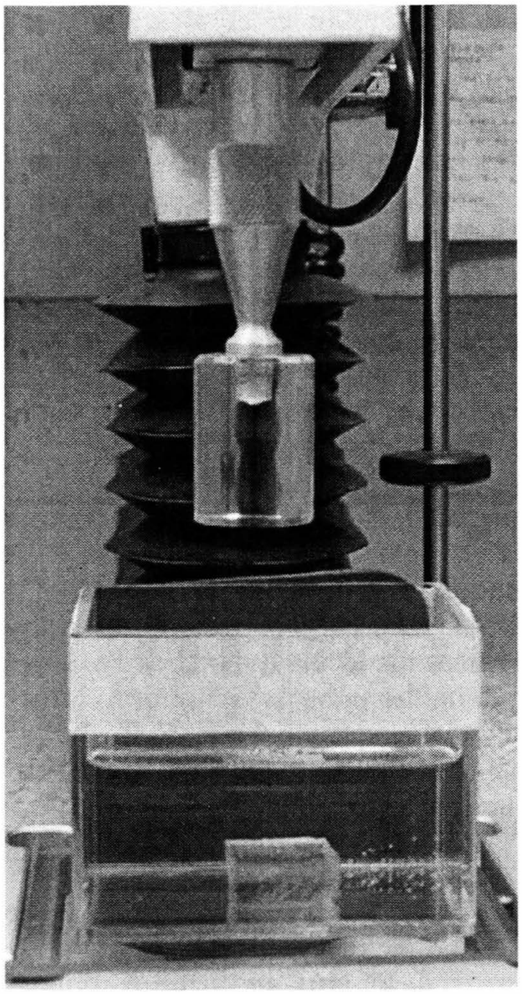

Figure 1. Picture of the TA.XTPlus with the 1 inch probe, testing container, and plexiglass platform.

Once the height of the freely resting hydrogel had been calculated, the TA.XTPlus was set to run a quasistatic test to an end displacement accounting for a 15% strain. All tests were conducted at a loading speed of .01 mm/s. Upon completion of the test, the load was removed from the sample. For all tests, the force was adjusted to zero at the sample height. Some error is present in the force measurements because the probe encountered additional force from the water buoyancy as it displaced further.

The sample was then loaded incrementally to allow pictures to be taken. The heights accounting for 1%, 2%, 5%, 7%, 10%, 12%, and 15% strains were determined and the probe was moved to each of these points at which point a picture was taken via remote. A picture was also taken with each hydrogel unloaded to establish a baseline contact area.

The pictures were subsequently analyzed with ImageJ. For each sample the scale (pixels per inch) was set based on the one inch probe used during the quasistatic tests. The contact circle diameter for each strain was subsequently measured using the software. The contact circle referred to is in reference to the contact circle formed on the plexiglass platform. In addition, the equatorial diameter was measured to allow the calculation of the elastic modulus.

Results and Discussion

The pictures at varying strains allowed the determination of the change in equatorial diameter as well as the change in contact circle diameter. Figures 2, 3, 4, 5, 6, 7, 8, and 9 are representations of the pictures obtained for a given sample. When analyzing the pictures using ImageJ, it was sometimes difficult to determine where the boundary of the contact circle was. In addition, at low strains the change in equatorial diameter is very small. Therefore, any slight change in the positioning of the length marker in ImageJ can produce a trend that would not follow the expected trend. The expected trend referred to here is the increase in equatorial diameter with increasing load. This trend should have held in this case because the probe and platform were significantly larger than the spherical hydrogel.

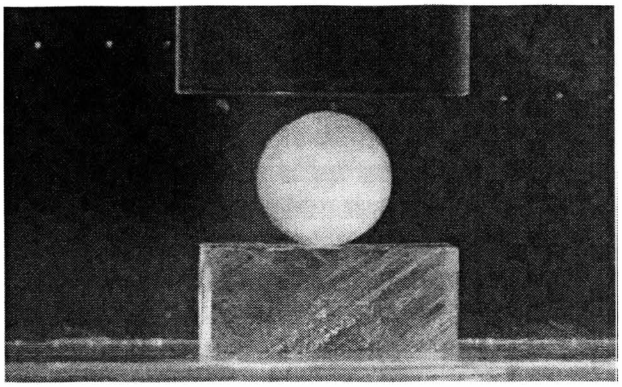

Figure 2. Picture of spherical hydrogel unloaded.

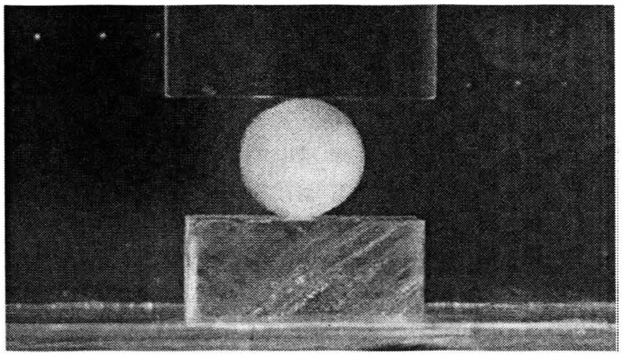

Figure 3. Picture of spherical hydrogel at 1% Strain.

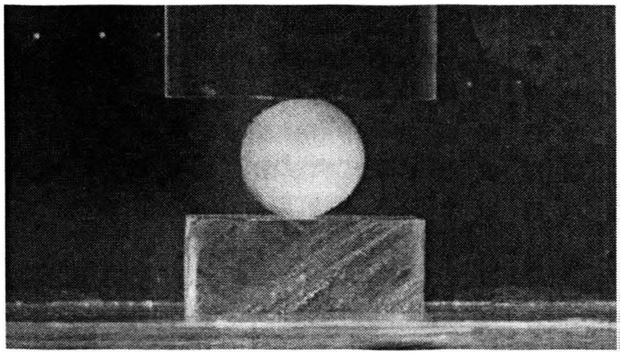

Figure 4. Picture of spherical hydrogel at 2% Strain.

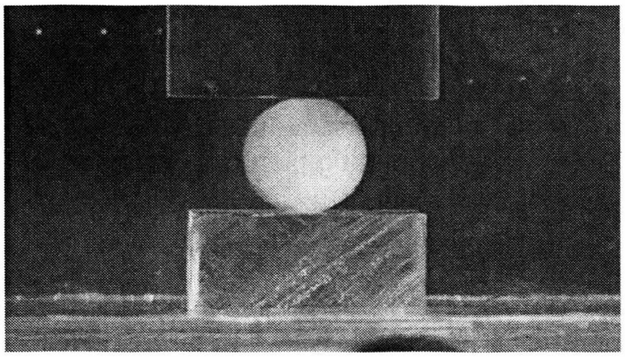

Figure 5. Picture of spherical hydrogel at 5% Strain.

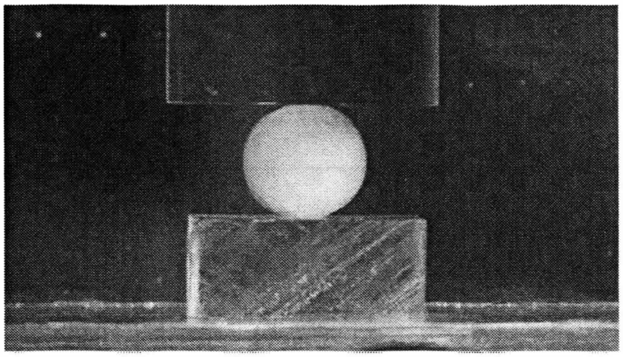

Figure 6. Picture of spherical hydrogel at 7% Strain.

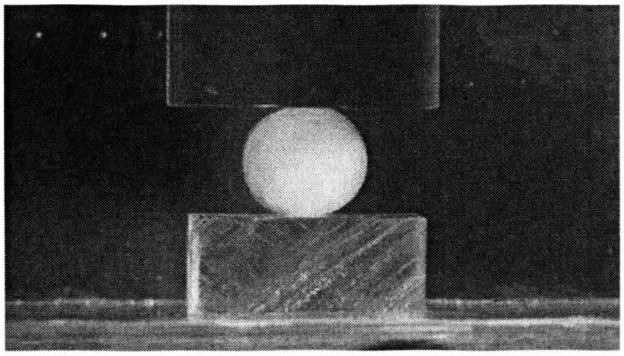

Figure 7. Picture of spherical hydrogel at 10% Strain.

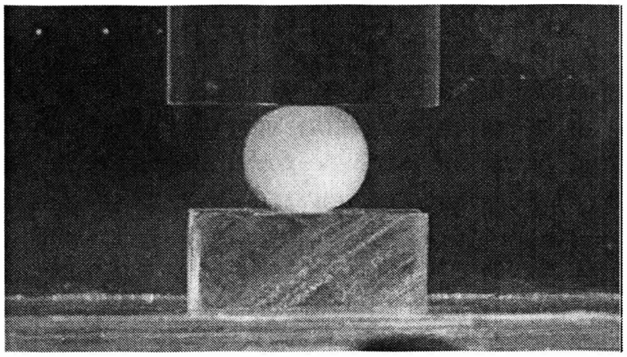

Figure 8. Picture of spherical hydrogel at 12% Strain.

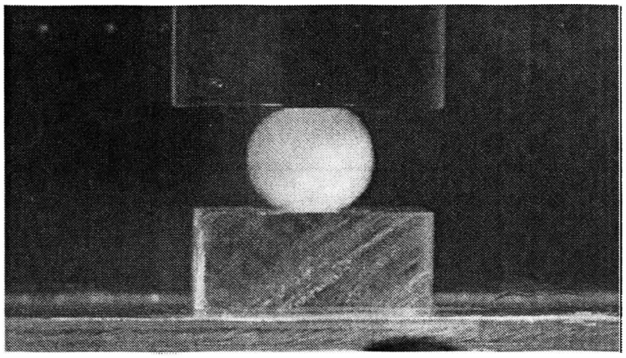

Figure 9. Picture of spherical hydrogel at 15% Strain.

The elastic modulus was calculated at each strain position based on a model given in previous literature.[1] The model used is shown below.

$$E = .16881\frac{F}{R_0 \Delta R} \tag{1}$$

E represents the elastic modulus. *F* is the load on the sample. R_0 is the radius of the uncompressed sample. R_0 was taken to be the radius of the unloaded hydrogel even though this gel is somewhat compressed due to its own weight and the weight of the water around it. ΔR is the equatorial radial increase due to loading.

The elastic modulus values found are shown in Table 1. These values and the contact circle diameter values shown later were based on three replicates (n=3). The values should have remained constant regardless of the strain. However, variation was present with varying strain rates. As is apparent in Table 1 and Figure 10, the elastic modulus values become more consistent when strains of 5% and larger are considered. The low values at strains of 1% and 2% could be the result of inaccurate measurements on the corresponding pictures at these strains.

Table 1. Elastic modulus values based on the entire range of strains and strains from 5% and higher.

E (kPa)	Std. Dev. (kPa)	E (kPa) for 5% Strains and Larger	Std. Dev. (kPa) for 5% Strains and Larger
3.459	1.263	4.071	.676

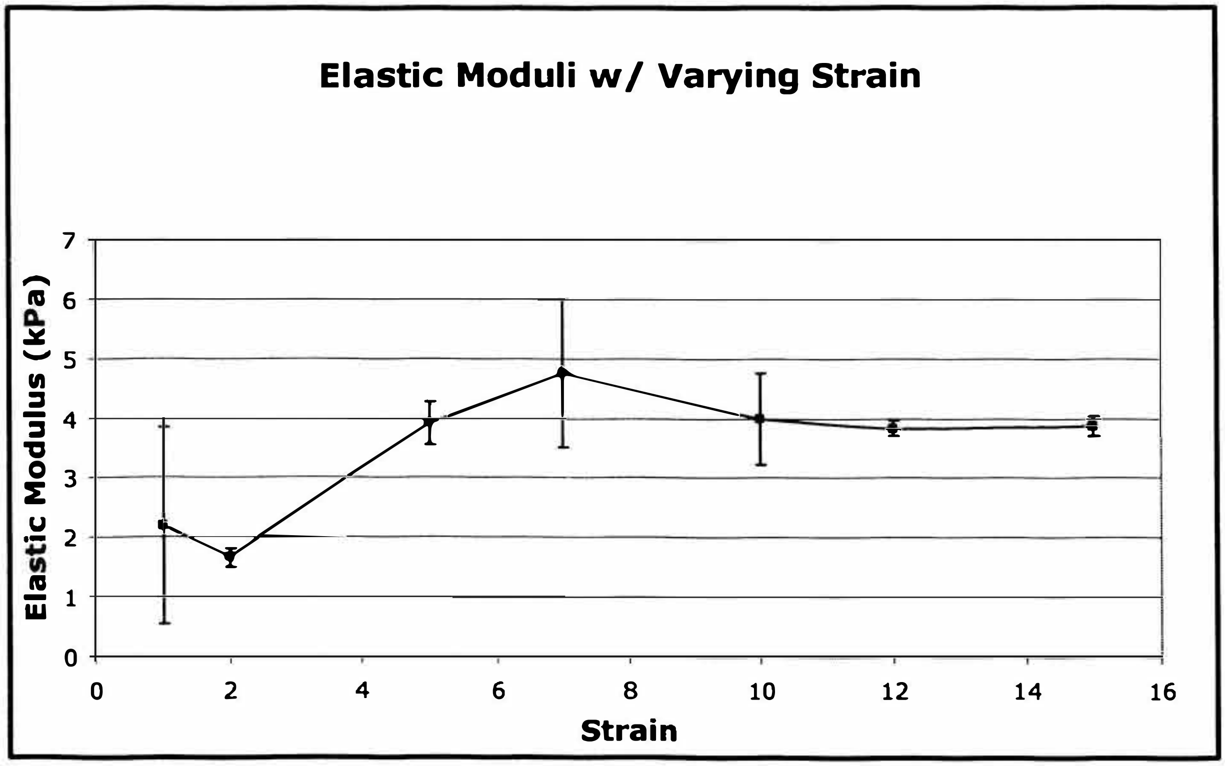

Figure 10. Plot of the elastic modulus values for varying strains.

The changing contact circle diameters were found from the pictures. The initial unloaded contact circle diameters are reported in Table 2. Clearly, there is somewhat of a variation in the resting contact circle diameter. This could be due to a couple problems.

First, the hydrogels were most likely not oriented identically on the platform, which could have caused variations if the hydrogels were not completely spherical. The third sample appeared to possibly be resting on a seam area created from the mold used to make the hydrogels. In addition, the measurements taken using ImageJ could have had error from interpreting where the boundary of the contact circle was.

The relationship between the changing contact circle diameter and the varying strains is shown in Figure 11. Based solely on the averages, there appears to be an approximately linear relationship between the two. However, the standard deviation was relatively large as indicated by the error bars. Again, this could have been caused by incorrect interpretation of the contact circle diameter when using ImageJ. It could also be caused if any of the spheres were more or less spherical than the others.

Table 2. Contact circle diameters for the unloaded spherical hydrogels.

Contact Circle Diameter (mm)		
Sample 1	Sample 2	Sample 3
2.410	1.431	3.592

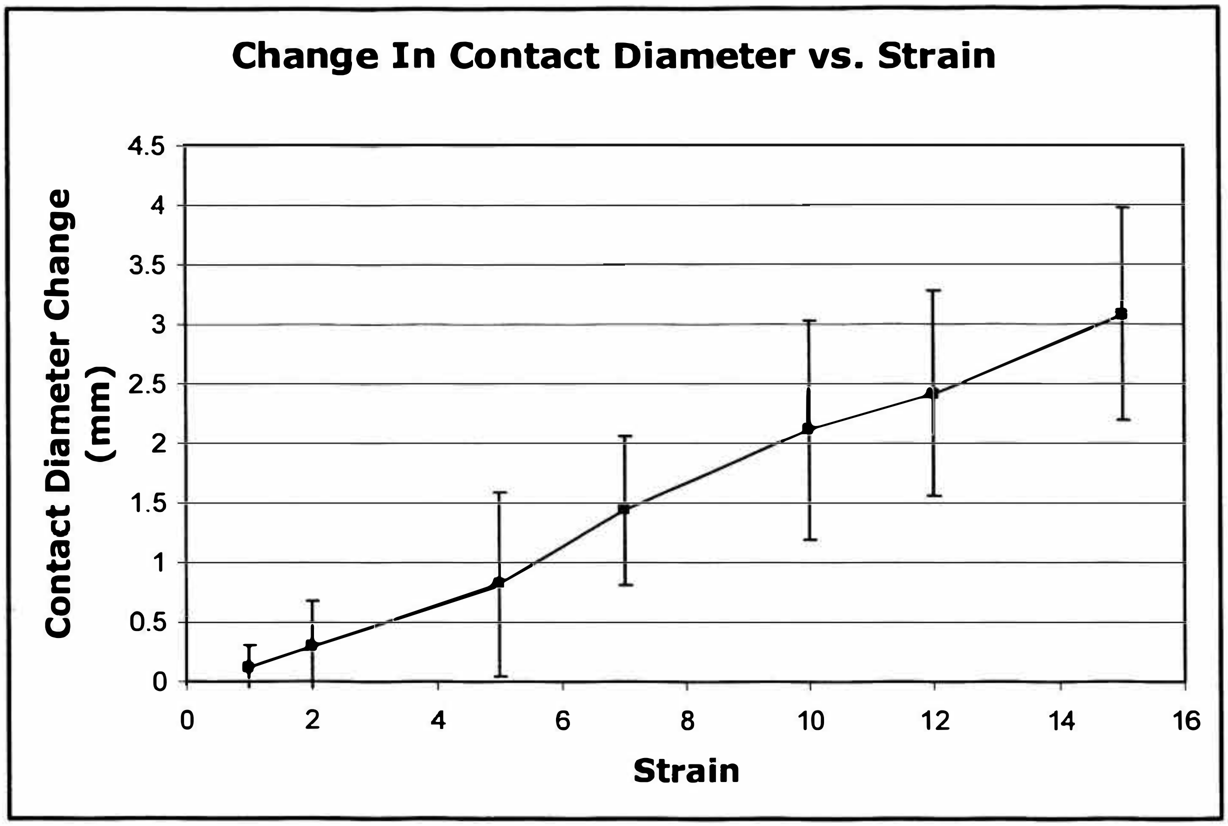

Figure 11. Plot of the change in contact circle diameter with respect to the initial diameter over varying strains.

Conclusions

It is thought that the main limitation currently is the precision with which the pictures can be interpreted. Despite the variations that were seen, a rather simple method was used to measure the contact circle diameter. To improve upon the precision of this method, care should be taken to maximize the quality of pictures taken at each strain. In addition, increasing the contrast between the platform and sample may produce more clear contact circle boundaries.

If the precision is improved, this method could serve as a relatively simple way to estimate the correlation between contact circle diameter and strain for other similar materials. In particular, natural ocular lenses could be tested. The contact circle diameters obtained could be compared to the results obtained for synthetic models to aid in the mechanical characteristic comparison of natural lenses to synthetic models.

Acknowledgements

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References

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