Effects of Strain Rate on the Viscoelastic Properties of Electrodeposited Alginate Hydrogels

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ABSTRACT

Alginate is a linear polysaccharide co-polymer that is currently used in a wide range of biomedical practices such as creating vasculature. This project relied on electrodeposition to create tubular alginate hydrogels with the potential for development of vasculature for further biomedical applications. In order to use these constructs, a better understanding of their viscoelastic properties, such as relaxation rate and amount of relaxation, is needed. We began by creating alginate hydrogel samples through use of an electric current to break apart calcium carbonate and had it combine with 1% w/v alginate in a phosphate buffered saline solution. In order to find certain properties such as stress, strain, relaxation rate, and amount of relaxation, we compressed the different samples of alginate at different rates with a Mach-1 Mechanical Tester until an amplitude of 0.75 mm was compressed. From this data, we were able to compare viscoelastic properties by compression rates of 0.03 mm/s (slow), 0.15 mm/s (moderate), and 0.3 mm/s (fast). Overall, we discovered that amount of relaxation and the relaxation rate peaked at the medium speed samples. Because alginate hydrogels are polymers and have viscoelastic properties, we expected for the relaxation rate to increase because more energy dissipates the slower a sample is compressed. Overall, our data contains helpful information on the viscoelastic properties of electrodeposited alginate hydrogels which can inform future studies in which compression rate is in important consideration.

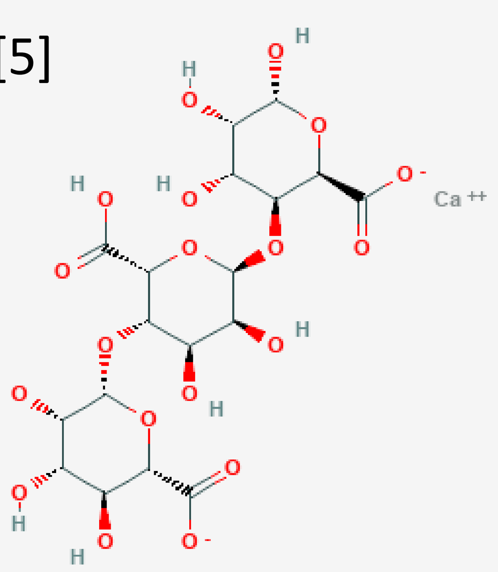
RESEARCH OBJECTIVES

- To identify viscoelastic properties of electrodeposited alginate gels using compression testing for use in further applications as a medium for creating vasculature
  - To study the effects of compression speed on viscoelastic properties such as stress, strain, relaxation rate, and amount of relaxation

BACKGROUND

Alginate hydrogels are being used in different biomedical applications such as in cell encapsulation, drug delivery, and tissue engineering. [1] Some labs have even used alginate hydrogels to create an injectable, cellularized nucleus pulposus that would restore spinal disc function. [2] However, there have been challenges in constructing three dimensional tissues in the area of tissue engineering, and in particular, researchers are looking into the construction of blood vessels. [3] Our lab focuses on the process of using electrodeposition, electrolyzing water to form H+ to react with Calcium Carbonate (CaCO3) to form Carbonic Acid and release Ca++ that reacts with alginate to develop tubular alginate hydrogels. Because it has been shown that stiffness of a material can affect differentiation of cells [4], it is important to consider the mechanical properties of alginate hydrogels. In order to test these properties, we used a Mach-1 Testing Machine to compress our samples. Compression testing is a method for determining mechanical properties, being able to apply and measure the force on a sample and measure displacement, which coupled with the physical properties of individual samples, are used to find the characteristic viscoelastic properties of alginate hydrogels.

[5]



Materials and Methods

- Created a 1% homogenous Alginate Solution in Phosphate Buffered Saline (PBS) and dissolved Calcium Carbonate in the solution to create a .5% Calcium Carbonate concentration.
- Created alginate gel tubes through electrodeposition by running 5.4 Volts of electricity through the solution for five minutes.

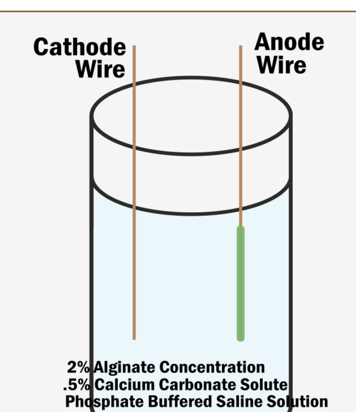


Figure 1: Model of Electrodeposition

MATERIALS & METHODS

- Cut gel using a thin .2 millimeter copper wire attached to forceps. Then measure the height, inner ring length, and ring thickness of each sample using an optical coherence tomography imaging test.
- Compress samples at speeds of 0.03 mm/s (slow), 0.15 mm/s per second (moderate), and 0.3 mm/s (fast) until a distance of 0.75 millimeters is compressed.
- Collected data for a period of two minutes after compression for gram force, time, and position using a PC-based data acquisition system.
- Calculated stress and strain and formulated charts in Excel for calculation of relaxation rate and amount of relaxation.

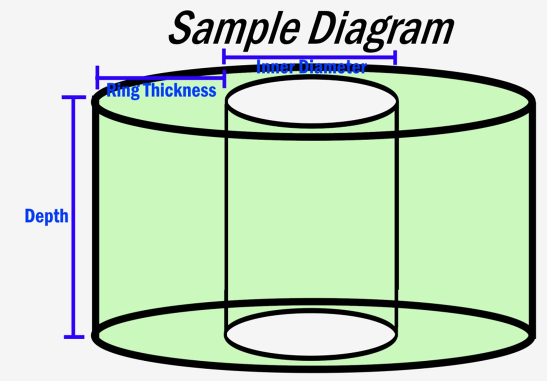


Figure 2: Model of Alginate Gel

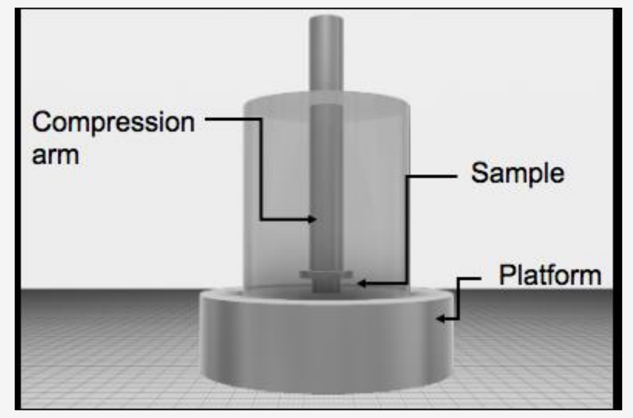


Figure 3: Model of Compression Test
Provided by David Kingsley

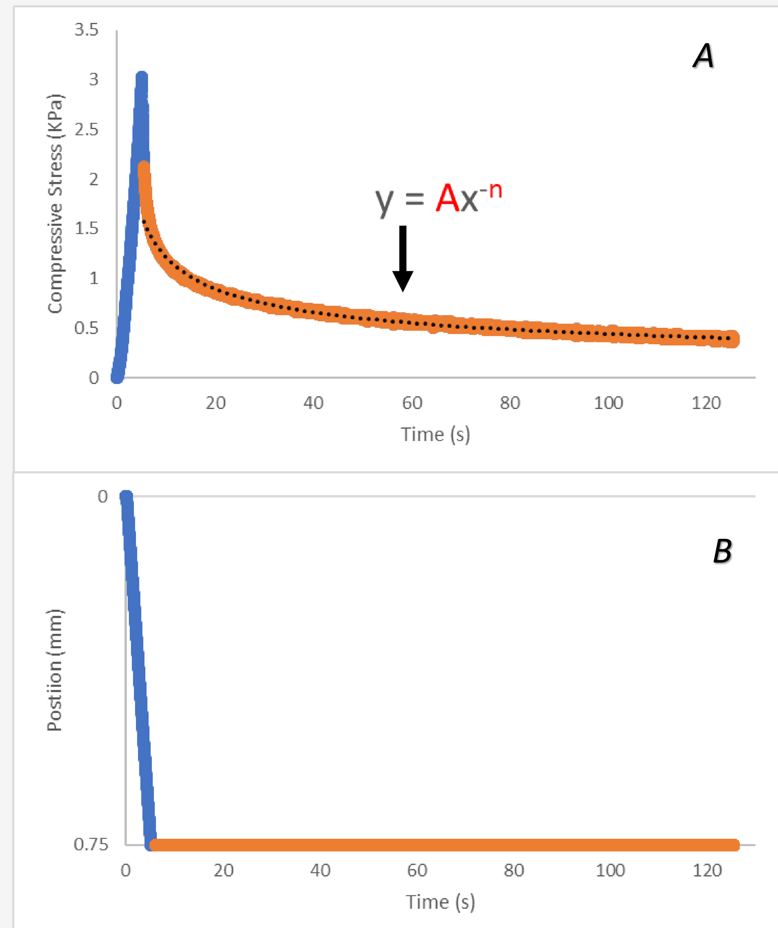


Figure 4: Stress vs Time Graph and Displacement vs Time Graph

A sample of a stress-time graph (A), where the alginate gels were allowed to relax for two minutes after compression to record amount of relaxation and rate of relaxation. The equation can be categorized into two parts, where the slope is the amount of relaxation and the coefficient was the relaxation rate. The second graph represents a position versus time graph that shows the displacement each sample goes during a compressing test (B).

RESULTS

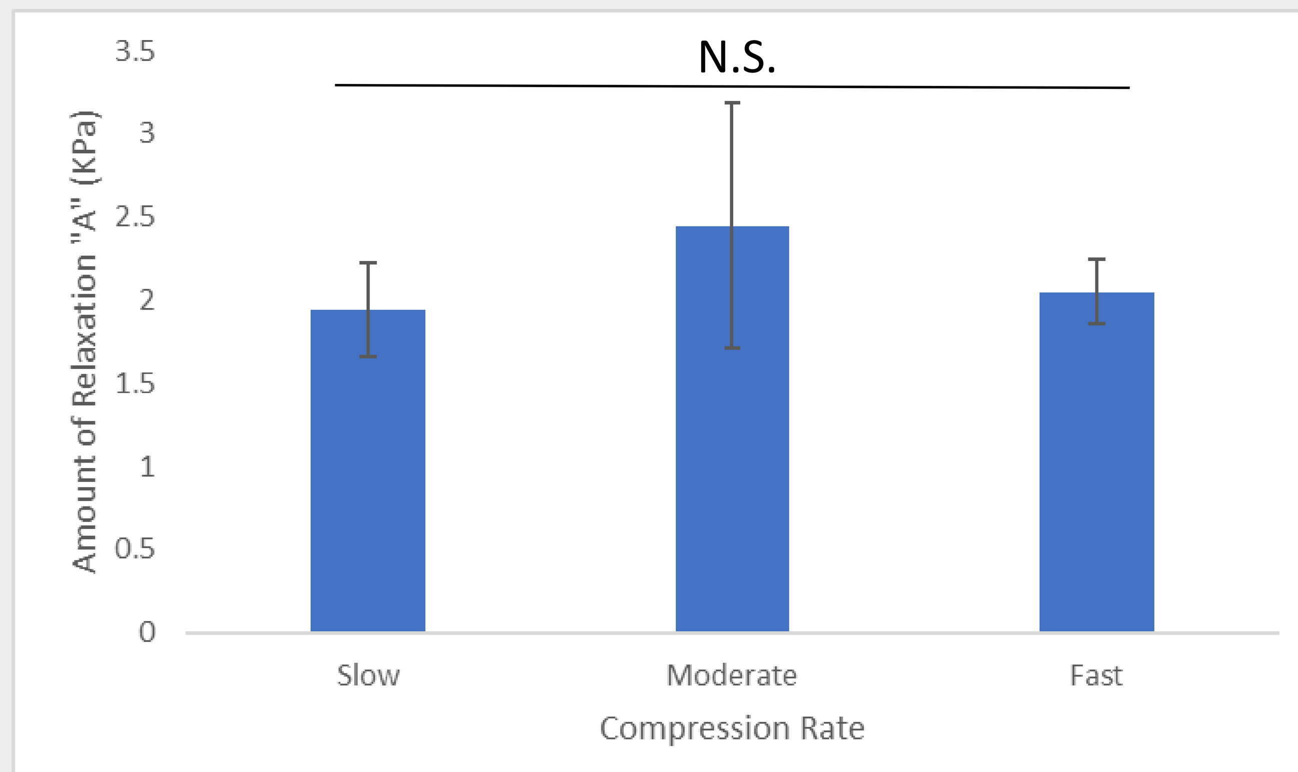


Figure 5: Graph of Relaxation Time at Three Different Stress Rates
After running a statistical ANOVA test, there was a P-Value of 0.38 for the amount of relaxation, which means there is no significant difference between the samples. Results shown are mean ± standard deviation.

RESULTS CONTINUED

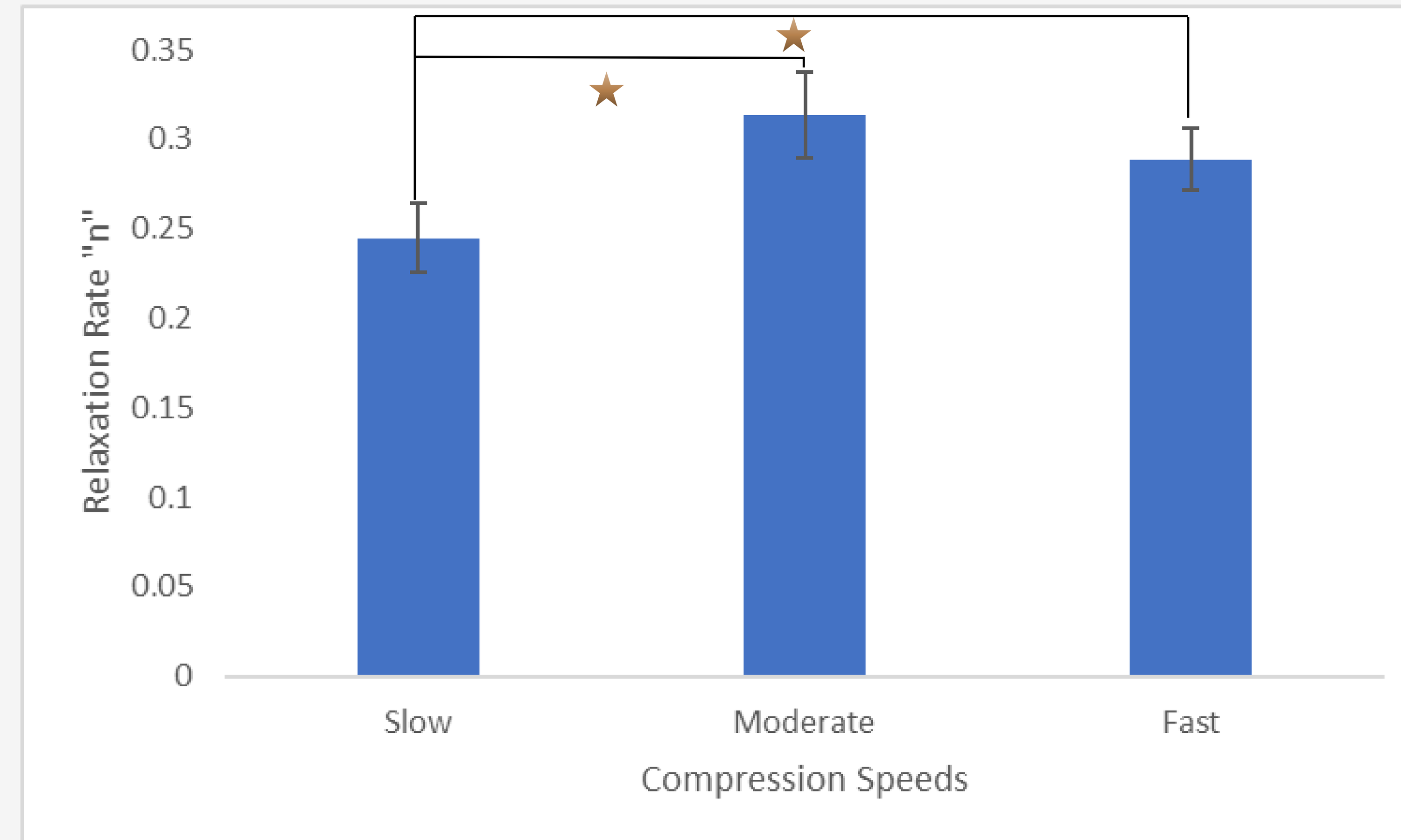


Figure 6: Graph of Relaxation Rate for Three Different Samples
For the relaxation rate, the P-Value is 0.0047, which signifies there was a statistical difference between the samples. After running three T-Tests between all the samples, the P-Value between the slow test and the moderate test was 0.0059288, demonstrating significance, and the P-value between the slow test and fast test was 0.0089944, also demonstrating significance.

CONCLUSIONS & FUTURE DIRECTIONS

Changing compression speed did not have a significant effect on the amount of relaxation seen in electrodeposited alginate gels. However, compressing the samples at a moderate speed resulted in the highest amount of relaxation on average. There was a difference in relaxation rates for slow tests versus moderate compression tests and slow tests versus fast compression tests, showing that relaxation rate increases with compression rate, yet there was no significant difference between the moderate relaxation rates and the fast relaxation rates, demonstrating that there is a threshold at which compression speed will not notably affect relaxation rate.

The data collected from this study can be expanded on and used in further fields. In the future, the viscoelastic properties studied here could be further tested at intermediate speeds to test the relaxation rates to get a better understanding of the viscoelastic properties of the gel and to determine the rate at which relaxation rate begins to stagnate when compression rate is increased. Since we only tested one type of alginate concentration and calcium carbonate concentration, we could test other different concentrations in order to test their relaxation properties to see if they could also be used to engineer vasculature.

ACKNOWLEDGEMENTS AND REFERENCES

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