BMES 460 Lab 3: Modelling to quantify Hydrogel Properties **Tasmia Hasan, 11/21/23**

Introduction: The time-dependent behavior of materials involves changes in a material's response or properties over time due to external forces or environmental conditions and can be used to study areas like fatigue resistance and wear of implants Hydrogels exhibit distinct viscoelastic properties, with features such as creep, where deformation occurs gradually over a period under a constant applied stress[1]. Understanding time-dependent behavior is crucial for unraveling how materials evolve, deform, or react to external factors across different time scales, influencing their mechanical characteristics and performance. Various models, such as Maxwell, and the standard linear solid (SLS), are employed to describe viscoelastic behavior[2]. This modeling approach allows for the prediction of material behavior, contributing to a comprehensive analysis of their mechanical characteristics. The aim of this lab is to look at how models can be applied to mechanical testing data to quantify the properties of two types of hydrogels. It is hypothesized that the SLS model will be an overall better fit for the stress relaxation tests.

Methods: Stress relaxation tests were conducted on 2% (by weight) gelatin hydrogels using the Bose ElectroForce 3200 Test Instrument. Two sets of gelatins were examined: one treated with de-ionized water (control experiment), and the other treated with glutaraldehyde (GL) for 30 minutes. The gel samples, each 13mm high with a diameter (d) of 1.5cm, underwent compression. The compression was applied rapidly at a rate of 20 N/s, initiated shortly after recordings began, and maintained for approximately 120 s. The strain (ε_0) was found to be -0.2. During this time, the load was measured in Newtons (N), and the displacement of the sensor was recorded in millimeters (mm). To calculate stress (σ), the applied load/force (F) was utilized in the formula: $\sigma = \frac{F}{\pi*(\frac{d}{2})^2}$

Two distinct models, the Maxwell model and the SLS model, were employed for analysis:

Maxwell Model: $\sigma(t) = E_1 * \varepsilon_0 * e^{(-t*\frac{E}{\eta})}$
Here, E represents the spring, and η represents the dashpot. The model combines these elements in series.

SLS Model: $\sigma(t) = \varepsilon_0\ [E_2 + E_1 * e^{(-t*\frac{E_1}{\eta})}]$
This model comprises the Maxwell model in parallel with a spring (E_1 and E_2) and η represents the dashpot.

MATLAB was employed for the dataset analysis. The curve fitting tool was utilized to obtain coefficient values for E_1, E_2, and η for both the models across the two types of hydrogels. Subsequently, these coefficients were incorporated into the respective equations, and graphical representations were generated.

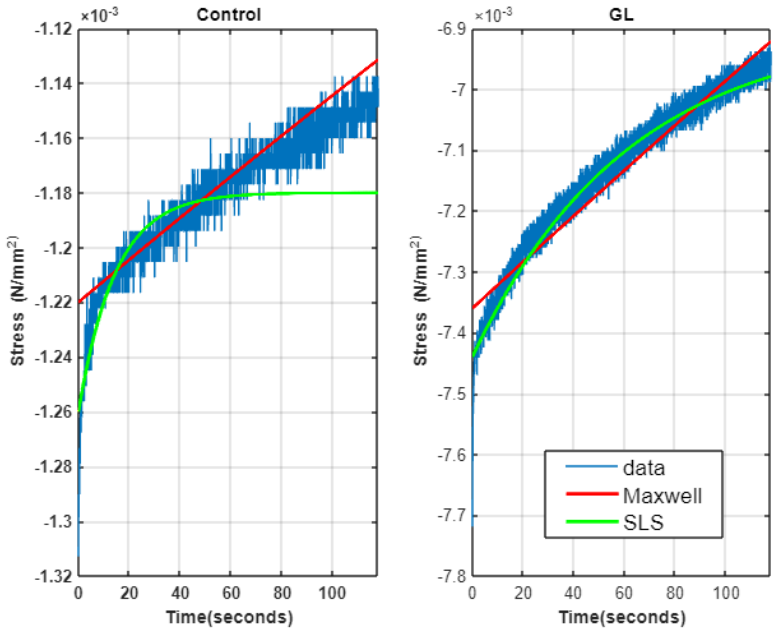

Figure 1: The graphs show the difference between the control and GL treatments along with the models applied to get the best fit.

2a. Control	$E_2(\frac{N}{mm^2})$	$E_1(\frac{N}{mm^2})$	$\eta(\frac{mm^2}{s})$	Adj R^2
Maxwell	0.0000	0.0061	9.5394	0.8507
SLS	0.0059	0.0004	0.0058	0.7085

2b. GL	$E_2(\frac{N}{mm^2})$	$E_1(\frac{N}{mm^2})$	$\eta(\frac{mm^2}{s})$	Adj R^2
Maxwell	0.0000	0.0368	70.5639	0.9301
SLS	0.0345	0.0027	0.1655	0.9680

Figure 2: The coefficients and adjusted R^2 for two models for Control and GL treatment in figures 2a and 2b respectively.

Results: Figure 1 shows that the hydrogels treated with GL had more negative stress values compared to the DI water treatment. Both the models in the both the treatment types passed through the actual data points. Adjusted R^2 (Adj R^2) was used as a goodness of fit measure, as shown in Figure 2 along with the coefficient values. Higher Adj R^2 show a better fit, hence a lower error. Thus, the SLS model for GL treatment showed the lowest error and the SLS model for the control experiment showed the highest error. Both the models showed a lower and similar error for the GL treatment data.

Discussion: The initial stages of stress relaxation may exhibit similarities, with both materials undergoing a rapid decrease in stress as they start to relax. The negative number accounts for the gels in compression. The more negative stress values in GL hydrogels indicate a pronounced stress relaxation response, due to enhanced cross-linking effects altering the gelatin matrix, as it makes it stiffer. DI water-treated hydrogels exhibit lower initial stress values and a less prominent stress relaxation profile. The SLS model's lower error for glutaraldehyde-treated gels suggests its appropriateness in capturing unique relaxation behavior. Limitations include model assumptions and potential variations due to experimental conditions. According to the Adj R^2 values, the Maxwell model is a better fit for DI water treatment and the SLS model is a better fit for the GL treated hydrogels. However, studies have shown the SLS model to be widely applicable to analyze viscoelastic properties of materials[2].

Conclusion: This experiment studies the importance of accurate modeling through curve fitting to characterize materials and predicting behavior. In the field of biomaterials, effective models, validated with experimental data, are crucial for optimizing properties, predicting biomechanical responses, such as ensuring mechanical integrity of implants over time.

References: [1] https://doi.org/10.3390/ma10050472 [2] https://doi.org/10.3390/polym14102124