

## Rheology of poly(glycerol sebacate)

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**Statement of Purpose:** The development of future biomaterials faces a major hurdle of compliance mismatch. Not only from a chemical but also from a physical perspective a biomaterial must closely match the properties of the native tissue the device is looking to replace. Poly(glycerol sebacate) (PGS) has garnered much attention over the past ten years in the area of regenerative medicine. The majority of studies have focused on the chemical interactions of the material with tissue and cells; i.e., chemical compliance. Based on the current analysis of PGS we hypothesize that the physical properties of PGS will be temperature dependent, which will have implications in development for future medical applications.

**Methods:** PGS was synthesized via a polycondensation reaction between glycerol (Sigma Aldrich) and sebacic acid (Sigma Aldrich). A 500mL reactor was charged with equimolar amounts of glycerol and sebacic acid. The reactor was heated to 130°C under a flow of N<sub>2</sub> to melt the sebacic acid and once melted the temperature was then lowered to 120°C and held under N<sub>2</sub> flow for 24 hours. Following the nitrogen step the reactor was placed under vacuum (~10 Torr) for 24 hours with the resultant material termed PGS. Additional curing was performed at 120°C/10 Torr to further progress the polymerization, e.g. PGS-24hr is PGS which underwent an additional 24 hours at 120°C/10 Torr.

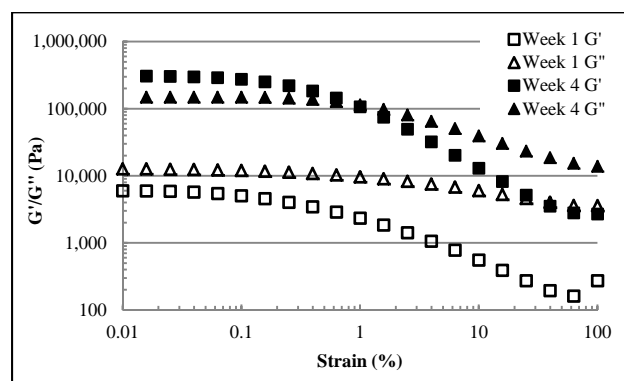
FTIR-ATR, DSC and rheology were performed on all PGS samples. FTIR-ATR data was collected on a Perkin Elmer Frontier fitted with a Universal ATR attachment (single bounce, diamond crystal). Thermal analysis was conducted using a Perkin Elmer DSC8500 using a heat-cool-heat method. Rotational and oscillatory rheological measurements were made using a parallel plate configuration on an Anton Parr MCR302.

**Results:** The extent of polymerization in PGS can be monitored using FTIR and DSC. Monitoring the carbonyl absorbance with FTIR allows for tracking of the polymerization progress as the acid carbonyl of sebacic acid decreases and the ester carbonyl absorbance of PGS increases as a function of polymerization time. DSC analysis shows that as the polymerization progresses the 1<sup>st</sup> melt enthalpy decreases indicating a lower degree of crystallinity. Also, both crystallization temperature and enthalpy decrease with increasing polymerization.

Rheological measurements show structural and morphological differences based on polymerization time, sample temperature and storage time. Amplitude sweeps performed on PGS at 25°C show a material where the loss modulus (G'') is greater than the storage modulus (G') indicating viscous or liquid behavior. However, measurements made over subsequent weeks show a change in the properties of the material. At two weeks G''

and G' begin to converge as the material becomes more gel like. At three weeks, a gelation point (~0.2% strain) is observed as the material transitions from a viscous to an elastic network. At four weeks G' is greater than G'' indicating a material with more elastic like properties and the gelation point has increased to 1% strain.

Sample temperature has a dramatic effect on the rheological properties of PGS which must be well understood for its potential use in the medical field. Amplitude sweeps conducted on PGS at 37°C show G'' an order of magnitude greater than G' as the material has reached its melt point and begins to flow. Unlike at 25°C, G'' remains greater than G' over the following three weeks, however there is a convergence of the two moduli, which likely reflects the network reorganization observed in PGS at 25°C. Furthermore, there is an order of magnitude decrease in both modulus values with the increase in temperature from 25 to 37°C, indicative of a material reaching its flow point.



**Figure 1.** Effect of time on the PGS polymer network structure. Amplitude sweep from 0.01 to 100% strain at 1Hz showing the relationship between G' and G'' values for PGS at weeks 1 and 4 post polymerization.

**Conclusions:** The characterization of PGS is important when evaluating both the polymerization and future use of this biomaterial. Rheological characterization has identified various properties of PGS which were previously unseen by other analytical techniques. At 25°C PGS appears to undergo a slow reorganization of the polymer network to reach the most stable morphology as illustrated by the transition from a viscous to an elastic network over the four weeks monitored in this study. However this reorganization observed at 25°C does not appear to affect the performance of PGS when tested at physiological temperatures as the material maintains viscous flow properties over the same time period. Currently, we are investigating the rheological properties of PGS with higher degrees of polymerization.