

Photocrosslinkable Networks with Tunable Mechanics

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Statement of Purpose: Recently, investigators have recognized the need to develop materials with elastomeric properties for a variety of applications, including for use in the engineering of soft tissues. Wang and colleagues synthesized a tough biodegradable elastomer, poly(glycerol sebacate) (PGS)¹. Although the mechanical properties and degradation kinetics of PGS can be designed to meet a given application², processing into complex scaffolds can be difficult, since curing requires high temperature and vacuum conditions^{1,3}. To impart more control over the crosslinking process, we designed an acrylated prepolymer that crosslinks in the presence of a photoinitiator and light. Photopolymerization for network formation offers several advantages, including improved spatial and temporal control, which allows for the fabrication of scaffolds with the desired structures for tissue engineering.

Methods: The prepolymer was formed using a condensation polymerization of glycerol and sebacic acid, as was previously reported¹. The prepolymer was split into four batches, dissolved in methylene chloride, triethylamine was added directly to each flask, and acryloyl chloride (1:10 in methylene chloride) was dripped into the solution at different molar ratios (OH: acryloyl chloride, 1:0.1, 1:0.2, 1:0.3, and 1:1). These values use an estimation that two of the three hydroxy groups present in glycerol reacted with the sebacic acid and provide a range of overall acrylations. After rotovapping the methylene chloride, ethyl acetate was added to the reaction flask, the solution was vacuum filtered to remove formed salts, and ethyl acetate was removed via rotovapping to leave a viscous liquid.

The condensation product and acrylated prepolymer were analyzed via GPC to determine molecular weights and ¹H NMR and Attenuated Total Internal Reflection Fourier Transform Infrared Spectroscopy (ATR-FTIR) to determine chemical structures. Networks were formed with the addition of 0.5 wt% 2,2-dimethoxy-2-2-phenylacetophenone (DMPA) and ultraviolet light for 10 minutes. Double bond conversion during polymerization was monitored using real time ATR-FTIR. Tensile testing was performed on samples (n=4-6) using an Instron 5848 mechanical tester with a 500 N load cell at a strain rate of 0.1%/sec. Finally, mesenchymal stem cells (MSCs) were cultured under standard culture conditions in the presence of the synthesized polymers.

Results/Discussion: The \overline{M}_w of the polycondensation product was determined to be 4.056 kDa and varied from 4.706 to 7.035 kDa post-acrylation. ¹H NMR of the polycondensation product showed peaks at 1.64, 2.31, and 2.37 ppm corresponding to the olefin chain from sebacic acid, multiplets at approximately 4 and 5 ppm due to the hydroxy and ether protons, and peaks at 5.9, 6.1, and 6.4 ppm characteristic of acrylate groups (data not shown).

The intensity of the peaks decreased as the molar ratio of acryloyl chloride decreased. This decrease was also evident in the ATR-FTIR spectra collected by a decrease in the intensity of the acrylate characteristic absorption at ~1635 cm⁻¹. The conversion of OH groups to acrylate groups clearly increases as the molar ratio of OH to acryloyl chloride during synthesis increases (Figure 1B). The characteristic acrylate peak decreased rapidly with ultraviolet light exposure (Figure 1A) and a maximum conversion was reached within three minutes. Additionally, the Young's modulus decreased as the molar ratio of acryloyl chloride decreased, whereas the % strain at break increased with decreased acrylation (Figure 1C). It is important to note that the 1:0.1 batch did not completely gel, and therefore mechanical testing was not performed. Moreover, all of the samples from the 1:0.3 and 1:0.2 batches broke at the clamp, thus possibly representing premature failure and low estimates for the % strain at break values. Finally, our preliminary work indicates that cells cultured in the presence of the synthesized polymers remain viable, indicating that the materials and degradation products may be cytocompatible.

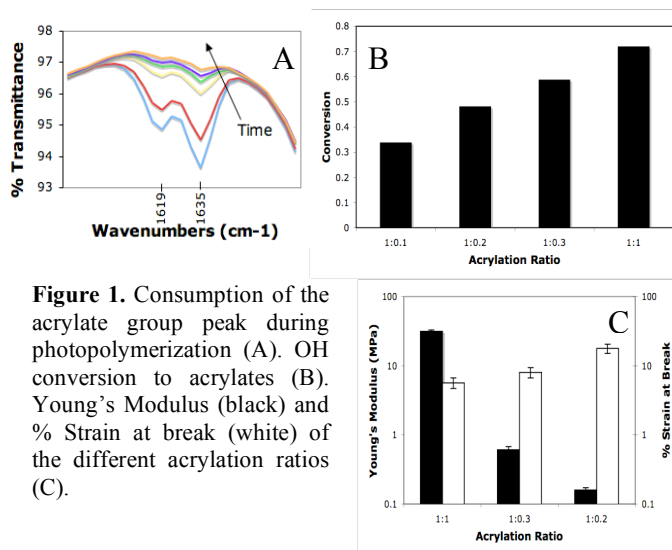


Figure 1. Consumption of the acrylate group during photopolymerization (A). OH conversion to acrylates (B). Young's Modulus (black) and % Strain at break (white) of the different acrylation ratios (C).

Conclusions: Photocrosslinkable polymers with tunable mechanical properties were successfully synthesized and photopolymerized. An increase in the acrylation ratio led to an increase in the Young's modulus and a decrease in % strain at break. Additionally, our preliminary work indicates that the networks polymerize quickly and are compatible with cells, thus strengthening the potential application of these materials for tissue engineering. Future work will investigate the effect of molecular weight and branching on network formation and mechanical properties.

References: (1) Wang Y. Nature Biotech. 2002; 20:602-606. (2) Gunatillake P. Eur Cell Mater. 2003; 5:1-16. (3) Goa J. Tissue Engr. 2006; 12: 917-925.