Solvent-cast 3D Printing with Different Molecular Weight Polymers

Tyler R. French[1], John W. Tolbert[1], Lesley W. Chow[1]

[1]Department of Materials Science and Engineering at Lehigh University Bethlehem, PA 18015

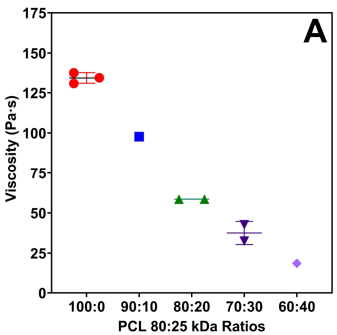
Introduction

- Solvent cast 3D printing (SCP) is a novel printing technique which involves dissolving polymer in a volatile solvent called "inks"
- Expanding the range of mechanical properties possible through SCP is important to create property gradients
- The goal of this project centers on characterizing how polymer molecular weight affects the mechanical properties of SCP scaffolds

Methods

- **Ink Formulation:** Inks were prepared with 370 mg/mL PCL total in three ratios of 80 kDa:25 kDa by weight: 100:0, 90:10, and 80:20. The PCL was dissolved into hexafluoroisopropanol (HFIP).
- **Printing Scaffolds and Fibers:** Inks were 3D-printed with a customized Nordson EV printer with 32-gauge needle at 70 psi or 56 psi depending on ink viscosity in an orthogonal pattern. The first layer was printed with line speed of 0.4mm/s and subsequent layers at 0.2 mm/s.
- **Rheology:** Stress growth experiments were performed using a TA Instruments Discovery Hybrid Rheometer-2 with a parallel plate set up. The inks were tested at room temperature at shear rates of 5 s^{-1} and 9 s^{-1}.
- **Imaging:** Scaffolds were sputter coated with iridium and imaged using a Hitachi 3500 scanning electron microscope (SEM). Fiber diameter measurements were taken using the open-source program ImageJ.
- **Tensile Testing:** Filament arrays of 25 filaments each 60mm in length were printed and mounted on paper guides. Arrays were tested using a Zwick/Roell Tensile Tester with a crosshead speed of 25 mm/min and a 100 N load cell.

Rheology Guides Printing Parameters



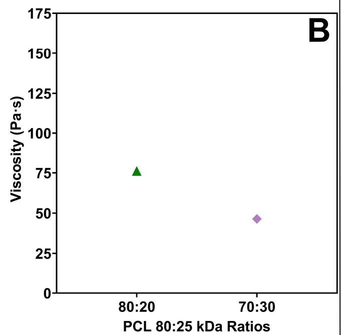


Figure 1: Viscosity (Pa·s) of inks containing different ratios of 80 and 25 kDa PCL at shear rates of (A) 9 s^{-1} and (B) 5 s^{-1} (N=1-3)

- Ink viscosity was matched to a predetermined set of print pressure and print speed to ensure consistent scaffold morphology across groups[1]
- Shear rates 5 s^{-1} and 9 s^{-1} correspond to print pressures 56 psi and 70 psi, respectively
- The viscosity of the 90:10 and 80:20 inks were much lower than the 100:0 ratios and were therefore printed with a lower print pressure based on prior work[1]
- Viscosity of inks with 70:30 and 60:40 ratios were too low for printing and were not included in subsequent experiments

Filament Stiffness

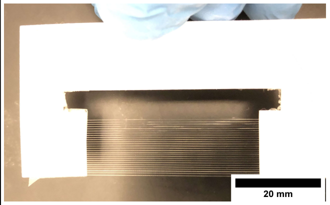


Figure 4: Macroscopic image of filament arrays in a paper guide for tensile testing.

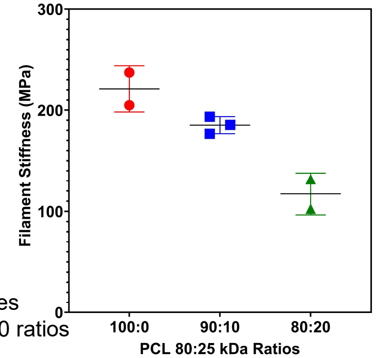


Figure 5: Filament stiffness values (MPa) for 100:0, 90:10, and 80:20 ratios (N=2-3)

- Increasing 25 kDa PCL content in the ink decreased filament stiffness
- Data shows that blending higher and lower MW species affects mechanical properties

Scaffold Architecture and Filament Diameter

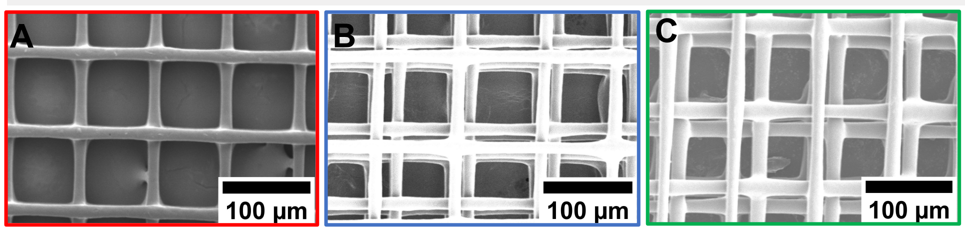


Figure 2: SEM images of (A) 100:0 (B) 90:10, and (C) 80:20 scaffolds

- Overall scaffold architecture similar between groups with small differences likely due to deformation during SEM sample preparation
- Filament morphology was similar across the different scaffold groups
- The filament diameter increased as the viscosity of the inks decreased

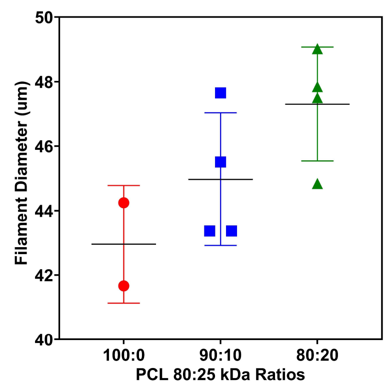


Figure 3: Filament diameters measured for 100:0, 90:10, and 80:20 scaffolds (N=2-4).

Conclusions and Future Work

- 80 kDa and 25 kDa PCL blends can be successfully printed using SCP
- Ink viscosity was used to identify optimal print parameters
- Filament morphology and diameter did not significantly change across different ink formulations
- Increasing amount of lower MW PCL reduced filament stiffness overall
- **Future work:**
  - Increase sample size for all experiments
  - Perform microindentation of bulk scaffolds
  - Blend with other MWs to expand range of mechanical properties

References: (1) J. W. Tolbert, D. E. Hammerstone, N. Yuchimiuk, J. E. Seppala, L. W. Chow, *Macromol Materials Engineering,* 2100442, 2021

Acknowledgement(s):

David and Lorraine Freed Undergraduate Research Symposium,
Lehigh University and the authors acknowledge Lehigh's Electron Microscopy and Nanofabrication Facility and Polymer Characterization Facilities. Polymers were generously provided by Polyscienced, Inc. This work was supported by the National Science Foundation (NSF) through a Faculty Early Career Development (CAREER) award (DMR 1944914 to LWC) and start-up funds from Lehigh University awarded to LWC