Research Statement

When stressed to failure, many materials fracture along cracks starting from small material defects and quickly propagating outward. Therefore, the study of crack propagation and the stress fields at crack tips, known as fracture mechanics, is foundational to understanding material strength and failure. My current research at Carleton with physics professor Helen Minsky focuses on fracture mechanics at the adhesive interface between glass and polydimethylsiloxane (PDMS), a common silicon-based soft polymer. We use a combination of finite element simulations, analytical models, and physical experiments to explore how material properties and system geometry affect crack propagation.

I seek to leverage my experience with professor Minsky by joining Dr. Kenneth Shull's research team at Northwestern University's Materials Science and Engineering department to study fracture mechanics in epoxy resins. Epoxy resins are used in most carbon fiber and fiberglass composites, which have many applications from wind turbine blades to high performance automotive parts to airplane fuselages and wing spars. To better understand how these common composites fail, it is essential to characterize the mechanical properties of their epoxy matrices, especially their susceptibility to fracture.

At the Shull lab, I will subject cured epoxy specimens to a wide range of mechanical tests, including tensile, indentation, crack propagation, and dynamic mechanical analysis (low frequency rheometry on the order of 1 Hz). In addition to these traditional mechanical tests, I will be responsible for carrying out high frequency rheometry using a quartz crystal resonator on the order of 10 MHz. While quartz resonators have been used as precision mass sensors for decades, their use as rheometers for thin polymer films is a new technique recently pioneered by the Shull research group [1]. The Shull lab's novel quartz resonator technique will be used to determine the complex shear modulus of thin epoxy films in the high frequency regime, which provides crucial insight into the material's response to high rate impacts. Taken as a whole, this testing suite aims to produce a comprehensive set of mechanical parameters for modeling fracture in epoxy resins.

In addition to testing several common epoxy resins used in composites today, I will synthesize and test a new type of epoxy resin which incorporates covalent disulfide bonds. These disulfide bonds can be repeatedly broken and reformed in the presence of a catalyst, allowing the new epoxies to be recycled [2]. Recyclable epoxies would enable the sustainable re-use of large epoxy-based composite parts like windmill blades, which currently end up in landfills after decommissioning. In certain scenarios, the ability to dynamically exchange and reform disulfide bonds could even facilitate the healing of micro-fractures, allowing damaged parts to be quickly repaired in space-based applications where replacement is not an option. As a result of these desirable properties, epoxy resins with dynamic covalent bonds have recently been the subject of significant research. My work would address the need for more detailed mechanical characterization of these recyclable, self-healing epoxies, especially in the context of high rate impact and fracture.

[1] G. C. DeNolf, L. F. Sturdy, and K. R. Shull, *High-Frequency Rheologica Characterization of Homogeneous Polymer Films with the Quartz Crystal Microbalance*, Langmuir **30**, 9731 (2014).

[2] A. Takahashi, T. Ohishi, R. Goseki, and H. Otsuka, *Degradable Epoxy Resins Prepared from Diepoxide Monomer with Dynamic Covalent Disulfide Linkage*, Polymer **82**, 319 (2016).