ENGINEERING
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Developing Icephobic Surfaces for Aircraft Industry Applications

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Introduction

My research aims to develop a deicing technology for aircraft without active energy input, human intervention and negative environmental consequences. Thus, we have focused on developing a one-time surface technology which aims to facilitate both deicing and anti-icing. Two main approaches include reducing interfacial shear strength (τ) and reducing interfacial toughness (Γ). Chemically we can also develop a surface with thermal hysteresis properties which aims to lower the freezing point of ice which can help stop ice adhesion at the start of the icing process.

Background

Need For Technology

The Aviation Accident Database of the National Transportation Safety Board reports that 228 aircraft accidents occurred because of icing from 2006-2010 with 40 accidents occurring during the flight. Apart from documented accidents, ice buildup on an airplane wing interferes with the normal airflow over a plane wing which reduces thrust and lift with weight and drag, clearly undesirable for an airplane. Ice is a present threat to aircraft technology, leading to hazardous and sometimes fatal accidents.

Figure 1. Hazardous ice formation on aircraft wing

De-icing

De-icing aims to detach ice that has already formed (ice shedding). For larger aircraft, “bleed air” systems are implemented where hot air is fed onto critical surfaces to halt ice accreditation. Additionally, thermal coils can be placed inside the surface itself to warm up the plane surface similar to a heated oven. These two de-icing technologies, while effective in many cases, are limited to larger aircraft and may have overheating concerns. Not to mention, they require additional power to maintain during flight.

Figure 2. Electrically powered heater de-icing a helicopter from glaze ice

Anti-Icing

Anti-icing is the process of stopping ice formation. One common fluid anti-icing technology uses antifreeze to chemically break down ice on vulnerable surfaces. These antifreeze molecules utilize thermal hysteresis properties to inhibit the growth of ice crystals at temperatures below the ice freezing point. While thermal hysteresis can effectively reduce ice freezing temperature, antifreeze molecules, which facilitate this hysteresis, have several negative environmental effects. Antifreeze is made up primarily of ethylene glycol or propylene glycol which forms metal contamination through corroding acid and potential health effects to the central nervous system if ingested. If possible, surfaces should aim to use safe chemicals without these harmful effects.

Figure 3. Spraying air and de-icing fluid over helicopter blades

Natural deep eutectic solvents (NADES) have demonstrated biomolecular activity, physiochemical properties, and component properties. In order to utilize these components under thermal hysteresis, a mixture of natural metabolites must be combined under a specific molar ratio in order to melt under the eutectic point. There is potential to use these as surface materials which can effectively delay ice accreditation. In literature at least 39 aqueous NADES species have been described in the literature demonstrating the potential for water to be utilized in these systems.

Methods

Sample Fabrication

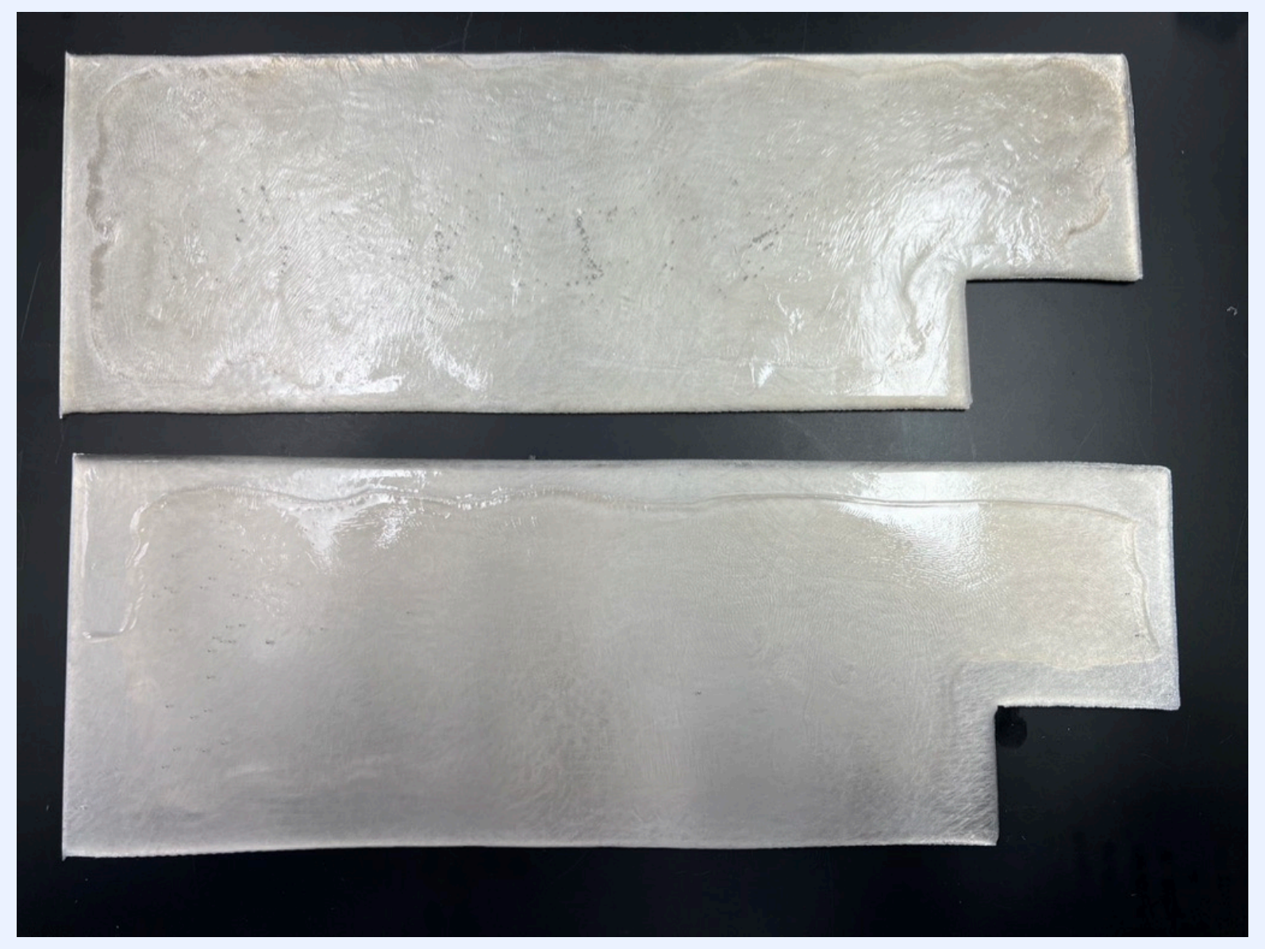


Figure 4. Bilayer samples, difficulty of fabrication process shown by defects on top sample

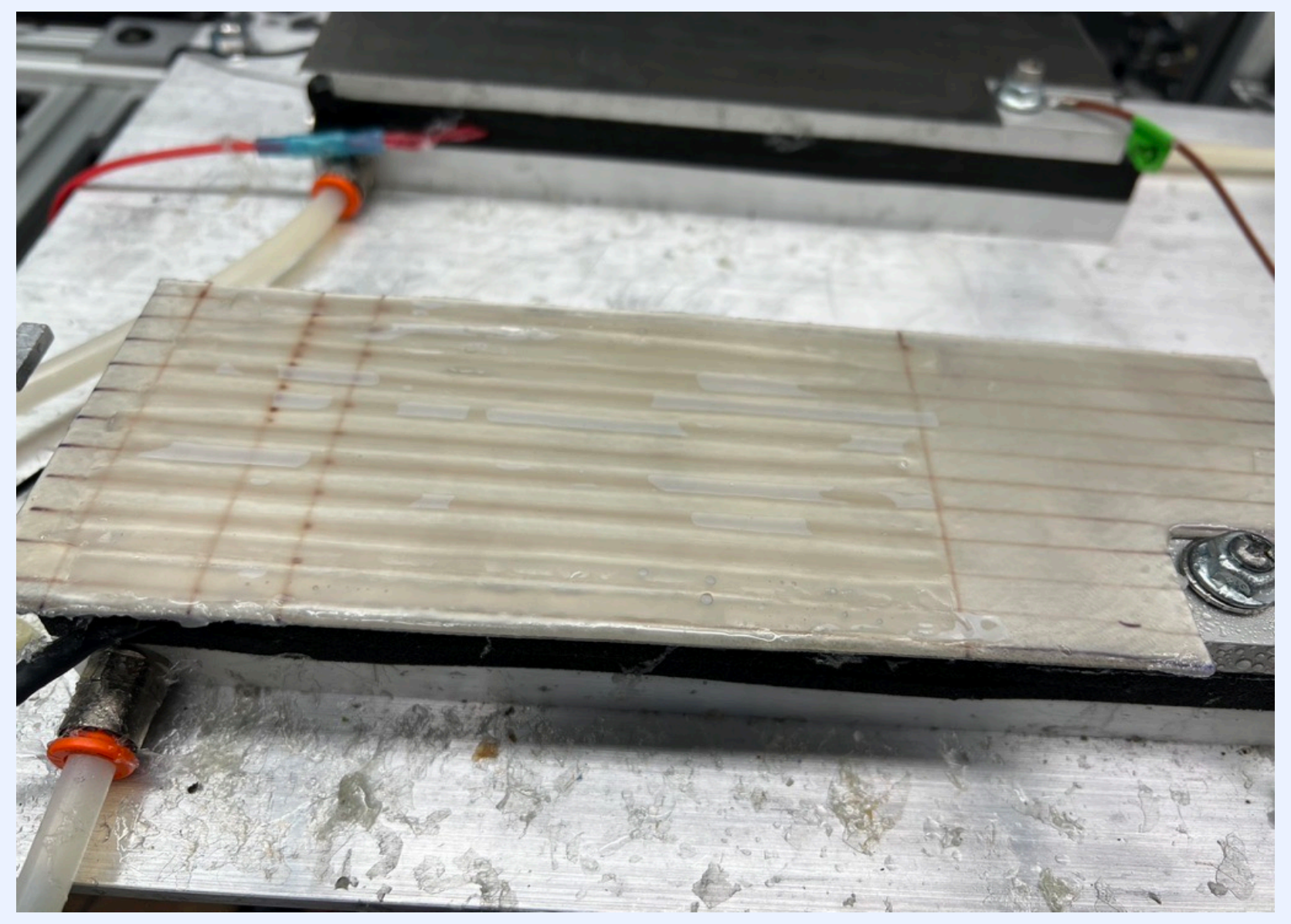
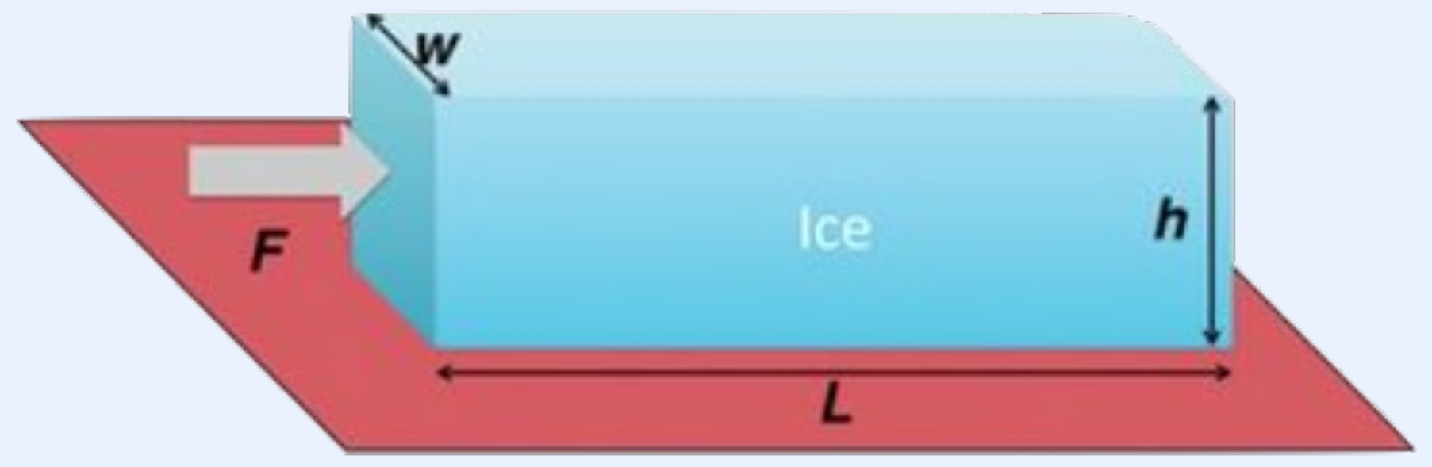
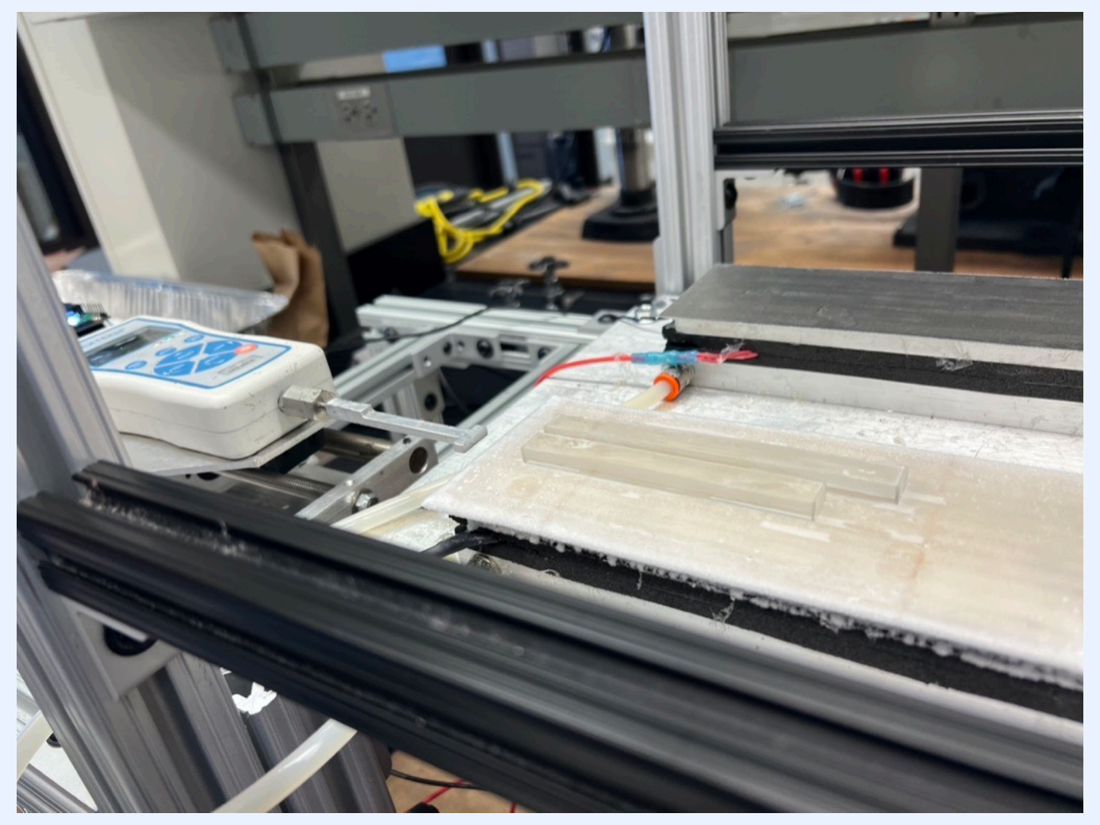


Figure 5. Thin film inserted between bilayers as an alternative sample fabrication method

Push-Off Test



Once ice cubes are adhered, a force is applied tangentially to the ice and the maximum force required to dislodge ice is recorded. This process is repeated 5 times for each sample at increasing ice lengths.



Interfacial shear strength (τ) is measured as the maximum force required to dislodge ice divided by the interfacial area.

The interfacial toughness (Γ) is measured by the critical force value squared divided by two times the ice modulus times and the ice thickness.

Differential Scanning Calorimetry

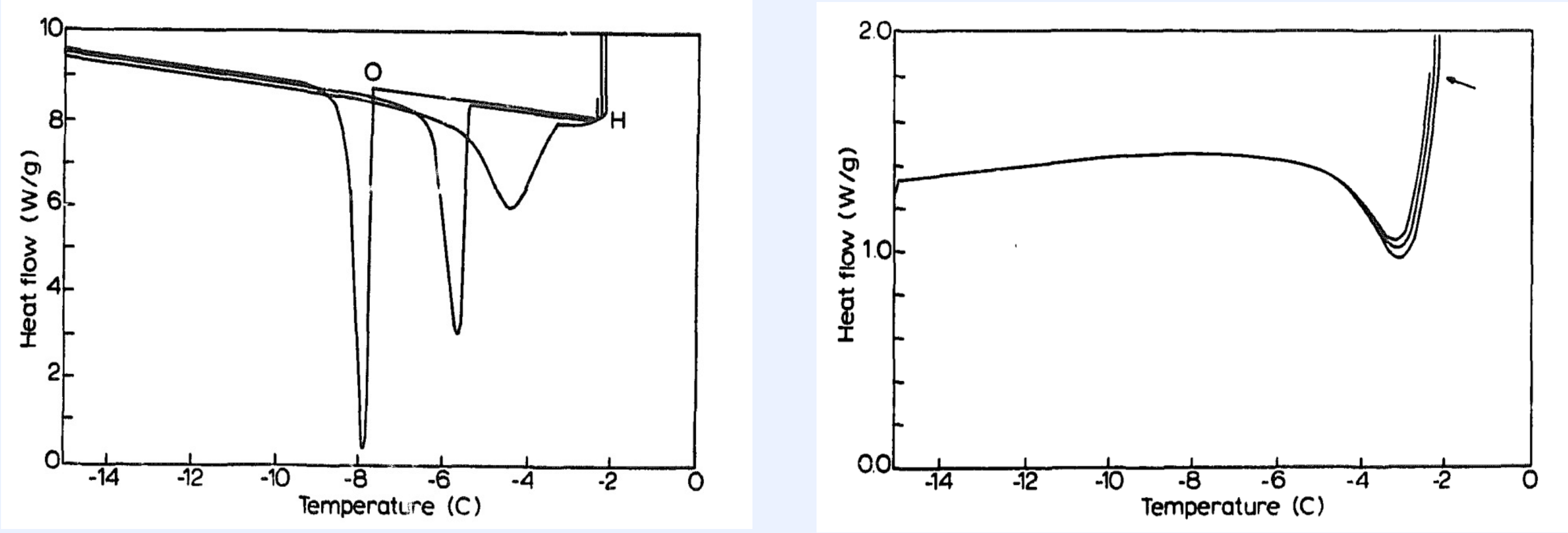


Figure 6. DSC thermograms of a hemolymph protein illustrating antifreeze protein activity on the left and no activity on the right. The three temperatures presented are - 2.3, - 2.2 and - 2.1 ° C. The delay in freeze onset increased as the temperature increased. The hysteresis sample's crystallization temperature was -23.3° C.

Results

Low Shear Strength (τ) – small scale spontaneous ice delamination

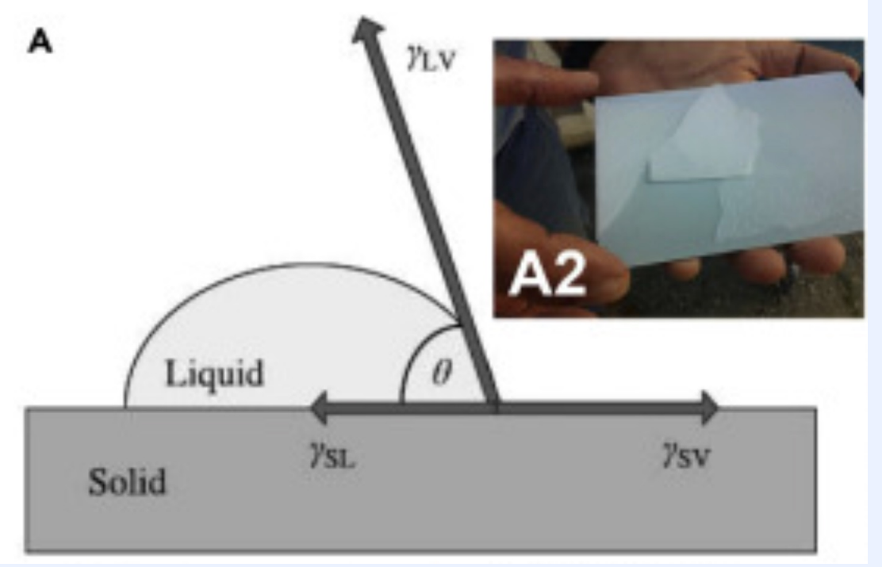


Figure 7. The work of adhesion to ice is quantified by utilizing the receding contact angle of water. A2 shows easily removed ice layer

Low Interfacial Toughness (Γ) – large scale, area independent, ice crack propagation

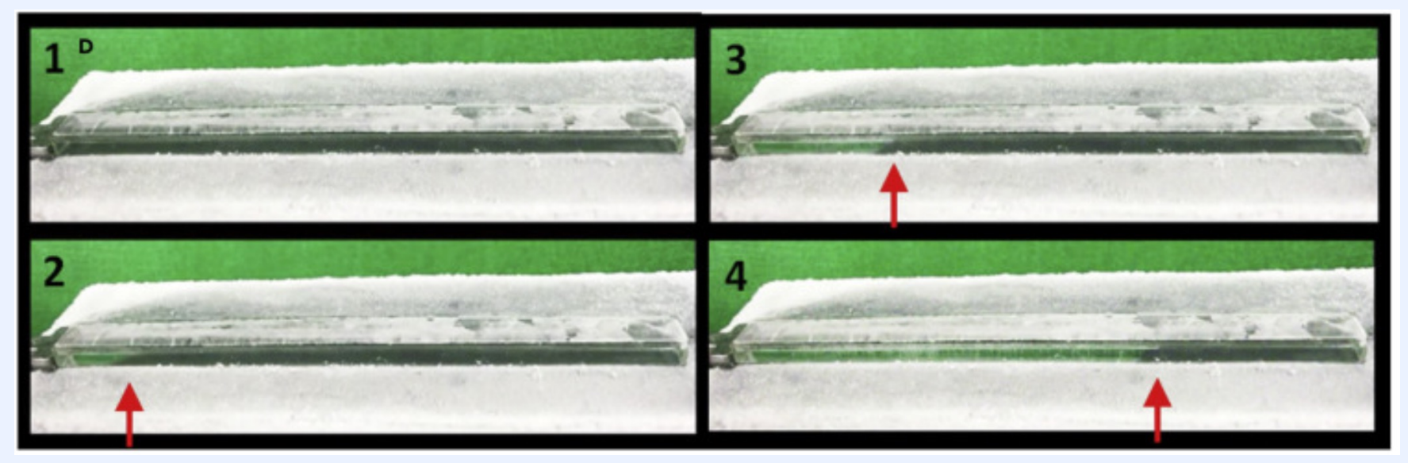


Figure 8. The delamination of a large piece of ice on polydimethylsiloxane (PDMS), facilitated by crack growth and propagation (marked with red arrow).

Results

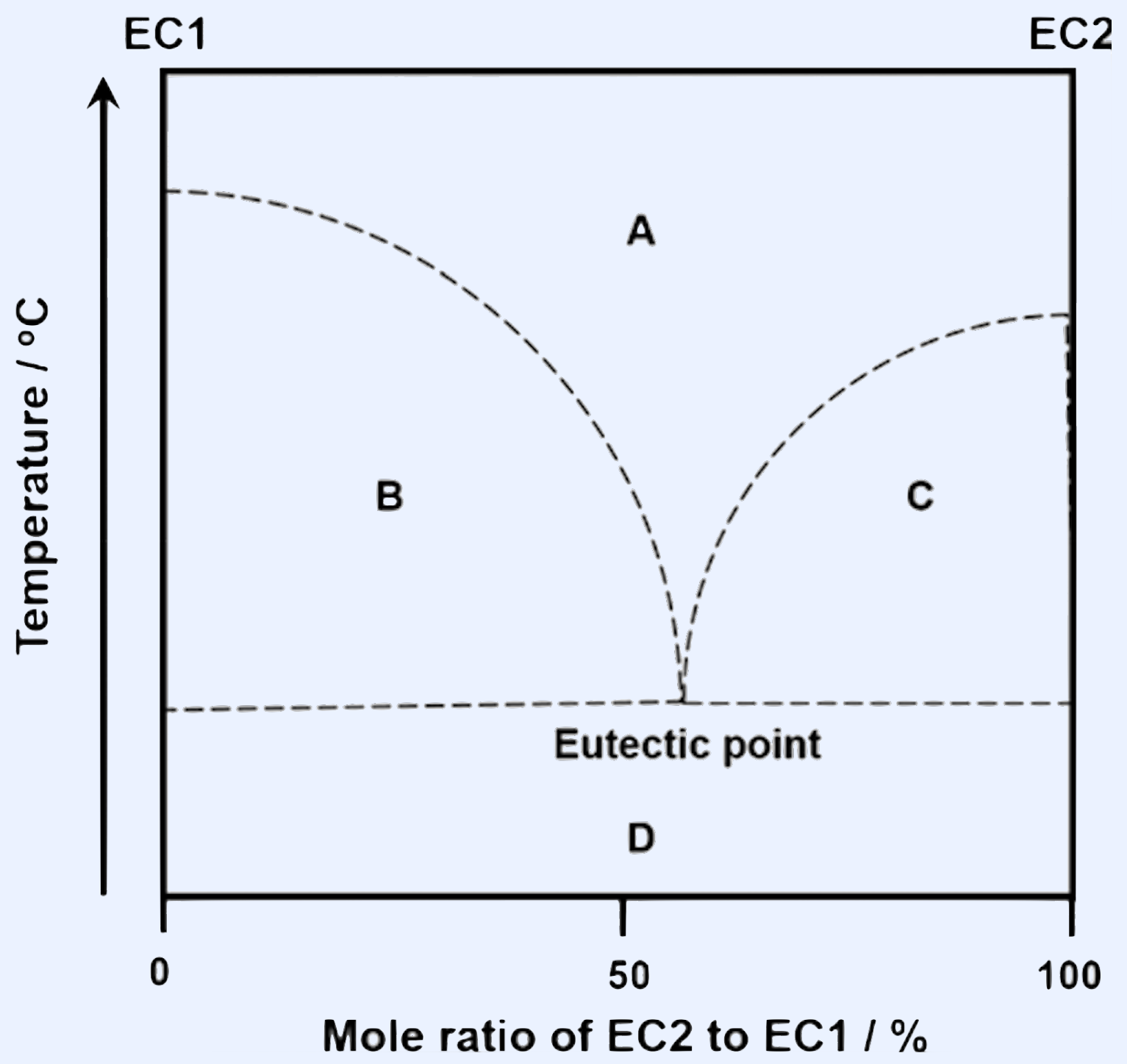


Figure 9. Eutectic point of two constituents demonstrating potential for a specific composition used to effectively lower the freezing point of water.

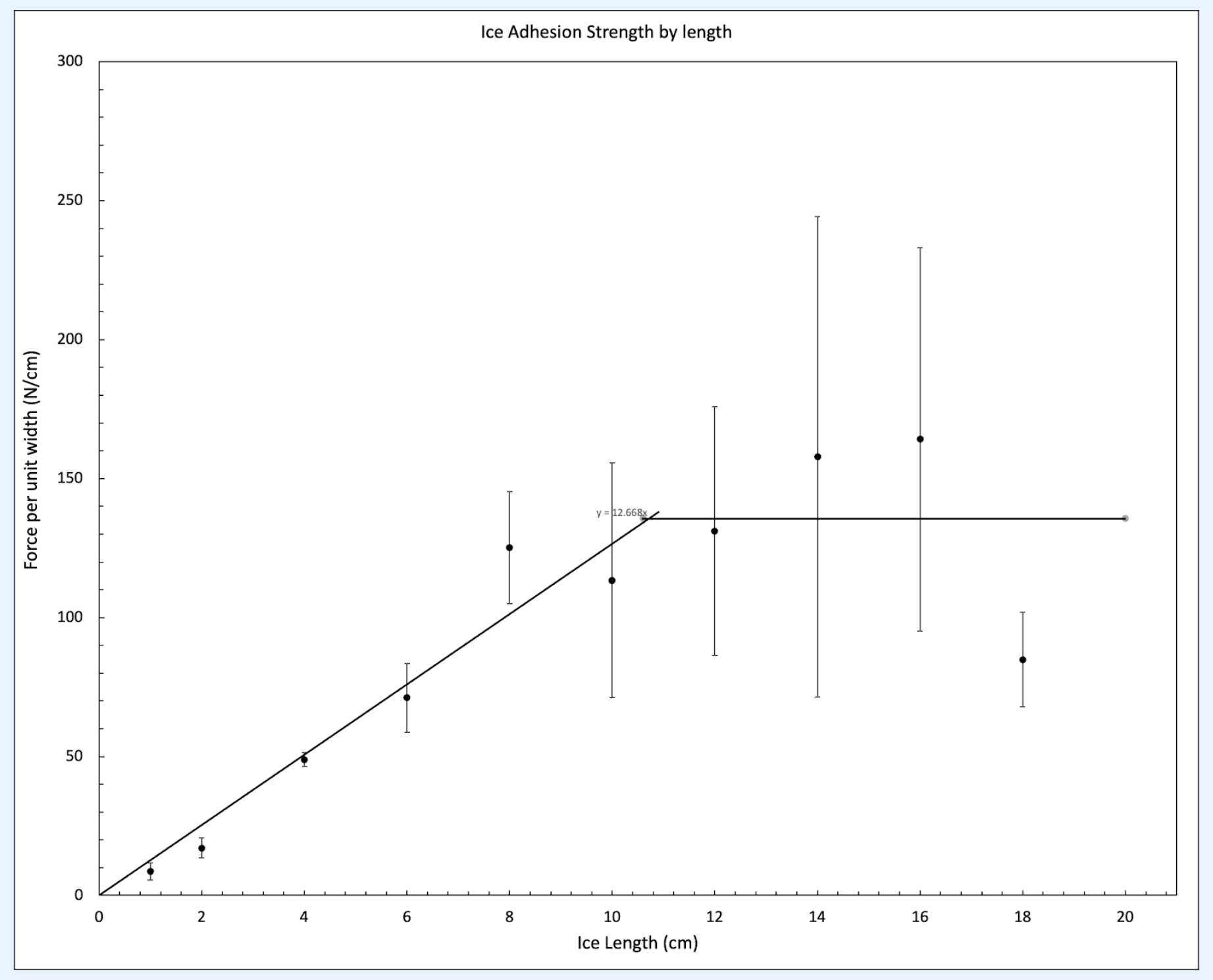


Figure 10: Force summarization of bilayer system demonstrating critical length of ice adhesion after which force becomes area independent.

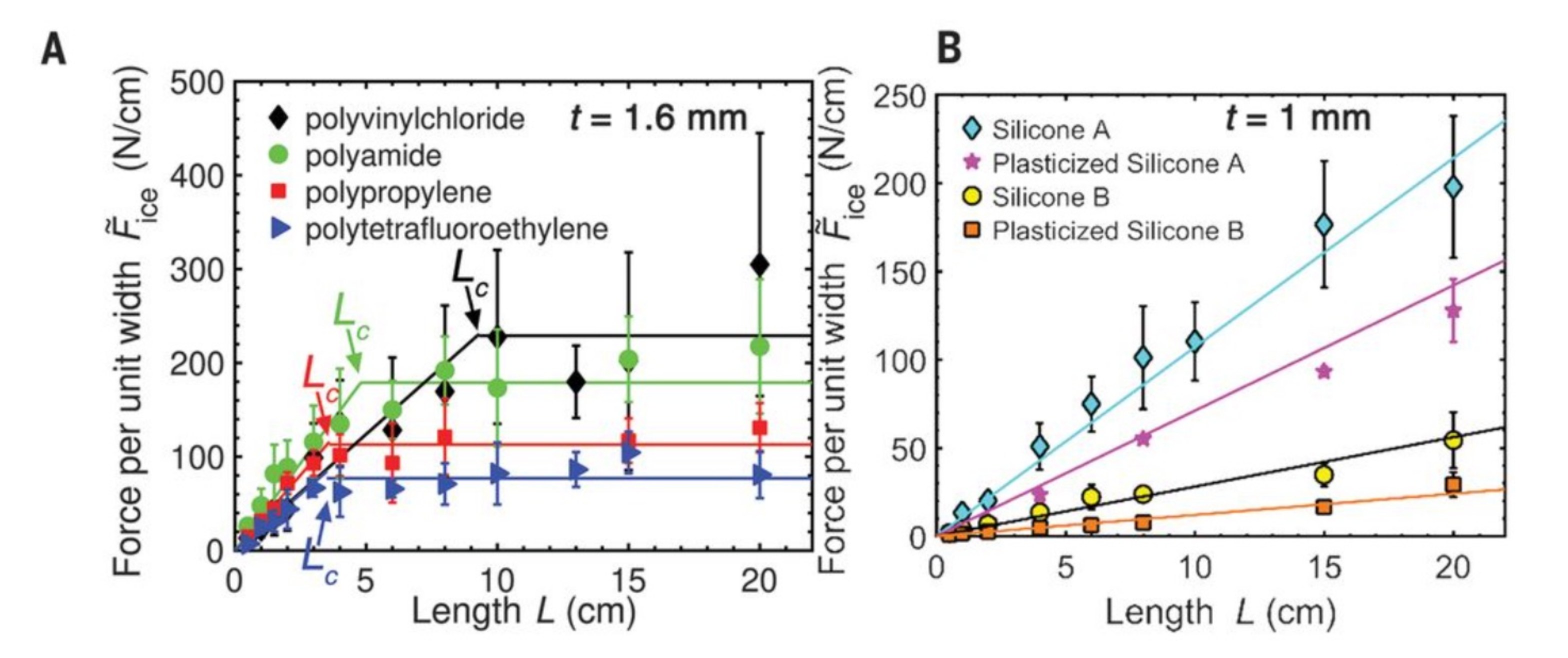


Figure 11: Comparison of several area dependent and area independent samples using push-off test

Conclusions/Future Work

- Reduction in ice adhesion strength and interfacial toughness has been observed in our bilayer systems.
- Non-toxic polymers with excellent adhesion
- Continue to test non-toxic polymers and to address de-icing and anti-icing possibilities
- Continue to minimize interfacial toughness and interfacial shear strength
- Persisting issues with complexity of fabrication processes and coating durability
- Possibility to use a spray coater to apply the de-icing agent onto the desired surface, better for industry usage

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