Abstract Draft for eMRS Conference

Title: **Reframing ice adhesion on surfaces: shear strength and toughness measurements with the horizontal push test.**

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Abstract

The negative effects of ice are well known and endanger equipment and human life. Due to many industrial applications where ice formation is relevant, several test methods have been developed to characterize ice adhesion on icephobic surfaces. However, there is currently no standard assessment for ice adhesion, and data from the literature show up to an order of magnitude difference in ice adhesion on the same material, depending on the testing technique and conditions. These discrepancies can be mostly attributed to an insufficient understanding of the ice fracture mechanisms: indeed, ice delamination from a substrate can be stress- or toughness-dominated. Most studies report an average shear stress value, expressed as the ratio of the applied force to the ice-substrate contact area. However, measuring a critical adhesion stress is only relevant in cases where ice delamination is stress-dominated. In case of toughness-dominated ice detachment, the calculation of the average shear stress becomes meaningless, resulting in errors of up to 400%. As such, material surface properties are incorrectly characterized.

This work provides a new method to fully characterize an ice-substrate interface using a horizontal push test, by measuring both critical shear stress and toughness. The horizontal push test is the most used ice adhesion characterization method by research groups involved in the development of anti-icing coatings and materials.

Using an experimental and numerical approach, we show that for a stress-dominated fracture mechanism, the stress value characterizing the surface adhesion is not the average shear stress, as previously assumed, but the minimum stress value over the entire interface. It is also shown how the fracture mechanism changes depending on the ice block size. However, depending on the substrate, the two fracture mechanisms may not be distinguishable by eye, which introduces errors in ice adhesion characterization experiments.

A complete characterization of the material surfaces is obtained by performing two tests with the same horizontal push test: for stress-dominated ice delamination, a smaller ice sample is used, while a larger ice sample is used to induce a toughness-dominated delamination. In both cases, the maximum ice removal force is recorded. For the stress-dominated case, the study proposes shear stress intensity factors (SSIF), which are used to calculate the minimum shear stress at the interface. Similarly, the ice removal force on the larger ice sample is used to calculate the interfacial toughness. Both the SSIFs and the toughness coefficients are given as a function of the test system geometry parameters, i.e., the ice sample diameter, the ice thickness, and the force application point. Therefore, the presented methodology can be adapted to already existing push tests, improving the characterization accuracy and the initial evaluation of the icephobic properties of novel anti-icing materials and coatings.