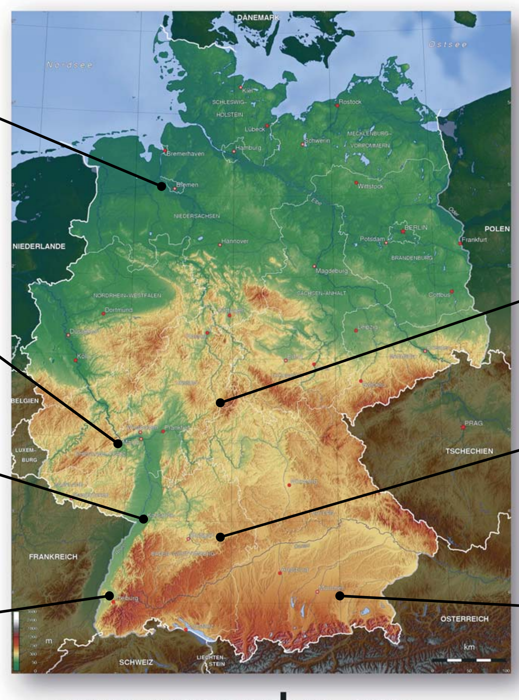

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PLASMA FUNCTIONALIZATION OF MULTI-SCALE STRUCTURED SURFACES TO CONTROL THE FORMATION OF ICE CRYSTALS

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Motivation

Currently, the topic “icing” is receiving more and more attention in many industrial areas, such as the design and operation of aircrafts, wind mills, or electrical networks. For aircrafts, de-icing before take-off is time consuming and expensive. State-of-the-art in-flight heating of the wings by exhaust gases (“bleed air”) consumes up to 30% of the engine power.

The aim of this project is to

- develop surface coatings on polymer foils

which allow

- influencing the formation of ice crystals and films,
- and to analyze and model the interfacial interactions (water–ice–coating).

Icing

Figure 1: Search-and-rescue helicopter: icing hazard

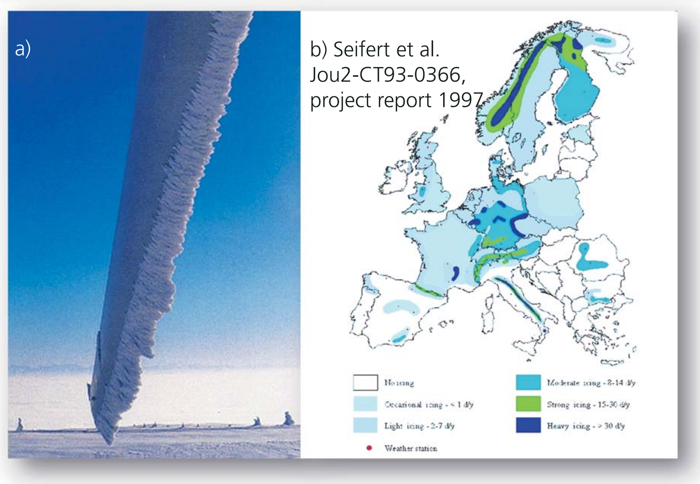


Figure 2: a) An example of extremely iced leading edge of a rotor blade b) European icing map: severity of in-cloud icing described

Results

Plasma Surface Functionalization

Polymer foils are chemically functionalized and structured on multiple scales (nano to micro scale) in order to control the wetting behavior and the ice-crystal growth. The chemical functionalization will be mainly done by PECVD of thin films of different chemical composition. The ice adhesion (de-icing) can be reduced by 90% in comparison to uncoated surfaces. Icing time (icing) can be increased by plasma coatings.

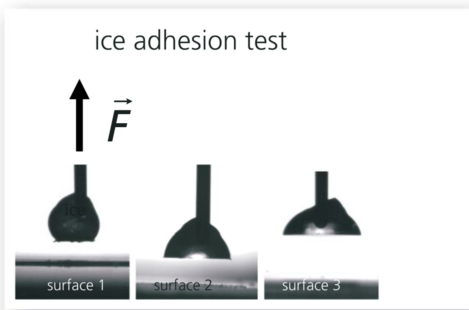


Figure 3: Adhesion test (surface temp. -18° C, atmosphere temp. 5° C, rH: < 5% in N_2)

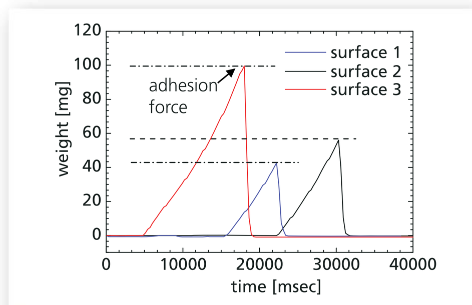


Figure 4: Examples of ice adhesion curves on different functionalized surfaces

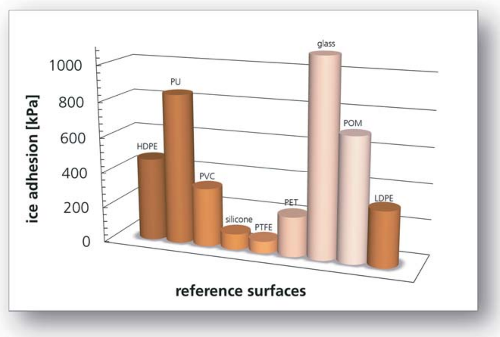
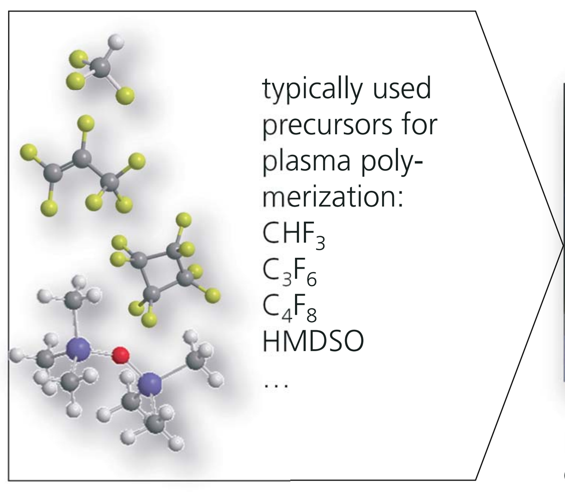
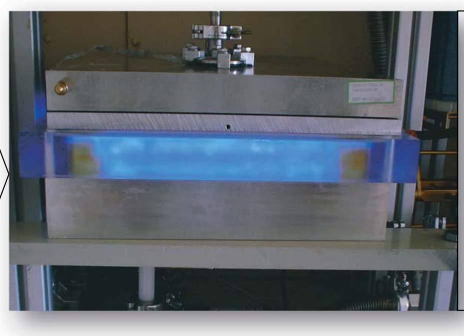


Figure 5: Ice adhesion on different reference surfaces





plasma reactor for process development (batch process)

next step: roll-coater (Pink thermosystems, ROWO coating)

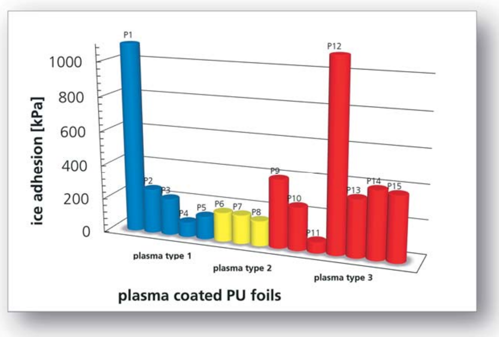


Figure 6: Ice adhesion on different plasma coated surfaces

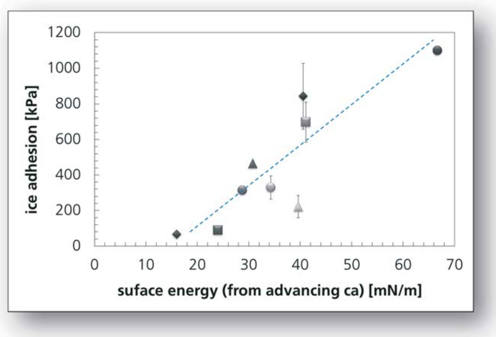


Figure 7: Ice adhesion in dependence of surface energy (correlation coefficient 0.88)

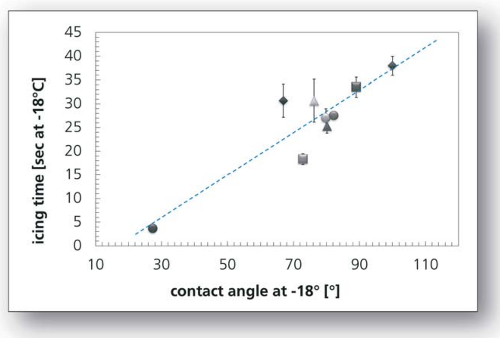


Figure 8: Icing time in dependence of contact angle (correlation coefficient 0.90)

Wind Tunnel and Icing Tests

For the evaluation of the functionalized surfaces, lab-based test methods will be developed. In order to achieve atmospheric icing conditions and to study the freezing delay/icing behavior on functionalized surfaces, supercooled water droplets are generated in a specially designed cryogenic chamber and wind tunnel. The wind tunnel allows the investigation of icing under real aerodynamic flow with wind speeds up to Mach 0.35.

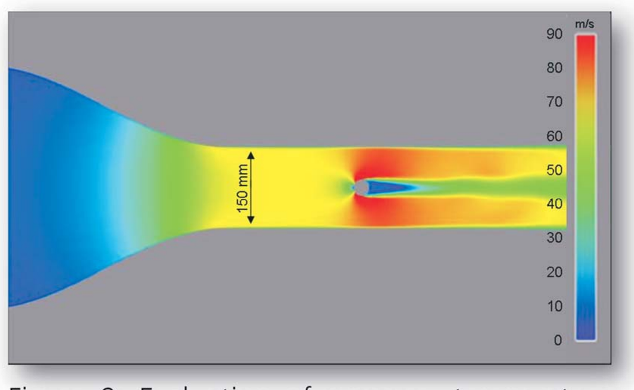


Figure 9: Evaluation of pressure, temperature and velocity distribution in the icing wind tunnel test section (here: numerical flow solution for a cylinder)

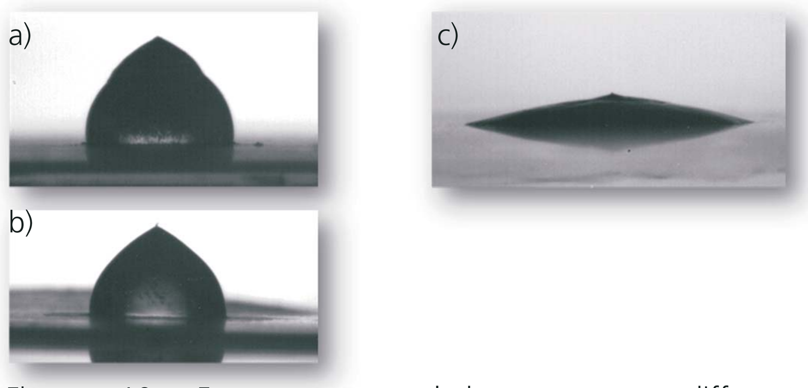


Figure 10: Frozen supercooled water on different functionalized surface in a cryogenic chamber at -18° C: a) plasma coated surface b) hydrophobic PTFE surface c) hydrophilic surface

Simulation

Multi-scale simulation methods (Figure 11, Figure 12) are going to be applied for a detailed description of the thermodynamic and kinetic aspects of the ice-formation process on functionalized surfaces, taking into account the special environmental conditions that may be encountered during flight.

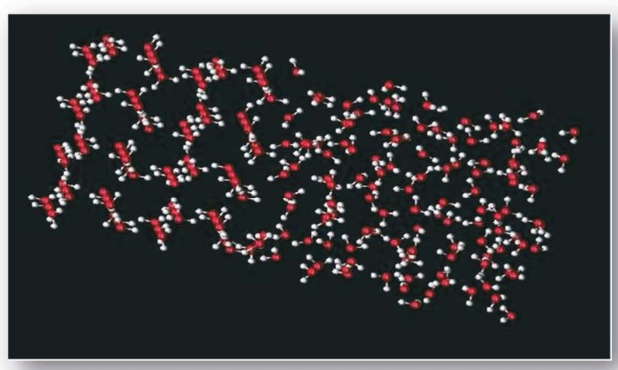


Figure 11: Snapshot of a growing ice crystal in contact with supercooled liquid water (disordered phase on the right). The water model employed is TIP4P/Ice

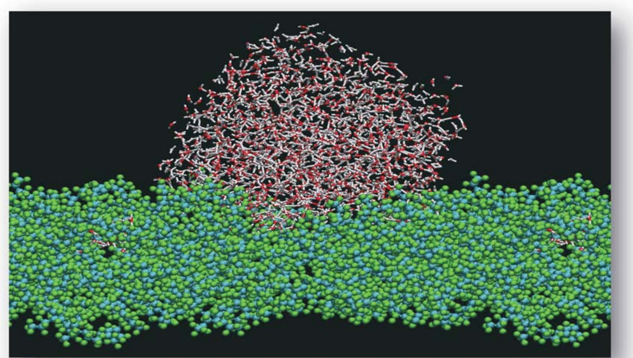


Figure 12: Simulation of a water droplet in contact with a PECVD coated, hydrophobic surface to determine the contact angle and to analyze the ice-crystal growth

Summary

The behavior of ice (icing + de-icing) can be influenced by changing the surface chemistry and surface topography by means of plasma functionalization. The ice adhesion and the growing of ice crystals was analyzed. With wind tunnel tests realistic flight conditions can be used to determine the icing and de-icing behavior on different functionalized polymer foils bonded to NACA profiles.

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