Topical Symposia
Room On Demand - Session TS1
Anti- and De-icing Surface Engineering

TS1-1 Role of the Thin Coating in the Durability of Icephobic Thin-on-Thick Coating Systems*, Stephen Brown (stephen.brown@polymtl.ca)**, J. Lengaigne,* Polytechnique Montreal, Canada*; N. Sharifi, A. Dolatabadi,* Concordia University, Canada*; L. Martinu, J. Klemberg-Sapieha,* Polytechnique Montreal, Canada

In-flight aircraft icing occurs when supercooled water droplets suspended in clouds collide with exposed aircraft surfaces. The buildup of ice increases the weight of the aircraft while also changing its shape, leading to an increase in fuel consumption and a decrease in lift and thrust. In the worst case scenarios, icing can also cause the malfunction of sensors or moving parts, leading to accidents. Of the potential solutions which exist, superhydrophobic surfaces (SHS) are among the most promising, due to their ability to repel water droplets at sub-zero temperatures and reduce the adhesion strength of any formed ice. When fabricating SHS, a common methodology is to create a surface which exhibits hierarchical roughness, and to coat this surface with a thin hydrophobic topcoat. While this method of fabrication is effective, it also means that the durability of the SHS is intrinsically linked to the durability of this topcoat.

In the present study, we develop a thin-on-thick superhydrophobic coating system, focusing on the durability of the thin hydrophobic layer. The thick portion of the coating system is hierarchically rough TiO_2, deposited by suspension plasma spraying, while the thin portion is a coating stack deposited by plasma enhanced chemical vapor deposition and is based on DLC:SiO_x—diamond-like carbon networked with silicon oxide. DLC:SiO_x was selected for its improved mechanical properties compared to other hydrophobic coatings, with the deposited films having a contact angle up to 95° and a hardness up to 11 GPa, and the whole thin-on-thick system having a contact angle of 159° and a contact angle hysteresis of 3.8°. Durability of the coatings is first assessed through icing/deicing cycling, and the results are compared to TiO_2 samples coated with commonly-used hydrophobic coatings, including stearic acid and fluoropolymer, as well as a sample coated with Rustoleum NeverWet. Following this, the most interesting coatings were subjected to rain erosion tests and accelerated aging tests. The thin-on-thick coating system is shown to offer improved durability over the others, maintaining water droplet mobility after 170 icing/deicing cycles, resisting prolonged UV and high-temperature exposure, and offering a 300-times improvement over the stearic acid in rain erosion tests.

TS1-2 Improving the Efficiency of Electro-Thermal De-Icing Systems With Icephobic Coatings*, Jack Brierley (emxjpb@nottingham.ac.uk)**, X. Hou, B. Turnbull, W. Sun,* University of Nottingham, UK

Active ice protection systems implemented in aerospace are incredibly power-hungry, but necessary safety feature. Applying icephobic coatings is a potential zero-energy passive solution to this problem. This study explores the viability of icephobic coatings to work alongside a thermal de-icing system to guide this field of research into designing a hybrid energy-saving solution. A coating that reduces ice adhesion strength passively is synergised with an electro-thermal de-icing system to make it more energy-efficient. Studies on the effects of surface roughness,coating thickness (Sylgard 184) and the implementation of thermally conductive fillers (silicon carbide fibres), have been carried out in the present work, to highlight a pathway for this combined solution: a hybrid system of an active heating system that is enhanced, and not limited by, an icephobic coating. The influence of surface treatment using 1H,1H,2H,2H-Perfluorooctyltriethoxysilane (POTS), a self-assembling monolayer to reduce the surface energy of the aluminium was also investigated. The inclusion of silicon carbide fibres in the PDMS coating provided a 5-fold reduction of energy consumption for de-icing was observed compared to pure polymer alone.The control of coating thickness was also a critical issue for both the ice adhesion and the energy consumption in de-icing. The design of an icephobic coating to focus on its specific operational environments is essential.

TS1-3 Icephobic Coatings by Thermal Spraying as Surface Engineering Technique*, Heli Koivuluoto (heli.koivuluoto@tuni.fi)**,* Tampere University , Finland*; R. Khammas, V. Donadei,* Tampere University, Finland

Icing causes challenges and serious problems in different industrial sectors e.g., in aviation, energy and construction as well as logistics. Increasingly, surface engineering offers various solutions to solve these challenges. However, still more sustainable solutions are needed and for this, thermal spraying as one of the surface engineering techniques opens a novel approach to produce icephobic coatings. These surfaces can act as potential passive anti-icing solutions in arctic environments. Thermal spraying technology makes it possible to produce coatings with a wide range of materials including metals, metal alloys, ceramics, composites, and polymers. Feedstock materials are fed to the thermal spray gun, where these are melted, heated, or accelerated towards a substrate or component surface to form a coating. Additionally, the material selection, coating structure and properties can be tailored with a thermal spray processing method where coating formation is based on either thermal or kinetic energy. Thermally sprayed icephobic coatings are typically polymer or composite based coatings with multifunctional characteristics e.g., wetting performance, slipperiness and protection against different wearing and corrosion conditions. These coating solutions can be divided into three categories such as thermally sprayed solid icephobic coatings (TS-SIC), thermally sprayed slippery liquid infused porous surfaces (TS-SLIPS) and thermally sprayed lubricated icephobic coatings (TS-LIC). These coating designs possess low to medium-low ice adhesion values measured with the centrifugal ice adhesion test (CAT). For the tests, ice was accreted in the icing wind tunnel (IWiT) at Tampere University (TAU) in ICE Laboratory. Generally, it can be noted that the lower ice adhesion leads to the higher icephobicity. Thermally sprayed icephobic coatings have shown their potential to avoid the icing of the components and minimize the adhesion between ice and the coating surfaces.

TS1-4 Limitations of Anti-icing Materials for Aeronautic Applications*, Paloma Garcia (garciagp@inta.es)**,* National Institute of Aerospace Technology, Spain*; J. Mora,* Isdefe, Spain*; A. Agüero,* National Institute of Aerospace Technology, Spain

Atmospheric icing is a severe issue which affects many different sectors in different ways: energy (Eolic), communications (power lines), or transport (trains, ships, aircrafts). In aeronautic, even a thin layer of ice, accreted in a few seconds, can be a serious problem, due to the possibility losing control which imposes accident risks. Modern aircrafts are equipped with effective systems to avoid ice accretion (anti-icing), or favour its release once it accretes (de-icing mode) over the sensitive surfaces.

These systems require energy, and an objective in this field is the use of more efficient systems to decrease the energy requirements, or alternatively, the development of material systems that do not accrete ice called anti-icing materials and therefore no energy supply is required during flights.

Icing mechanisms are not completely understood, and many different surface modification strategies have been explored without sufficient success in recent decades. Most of them are based on low wetting solutions (super-hydrophobicity and high water droplet mobility), low surface energy materials, or biomimetic strategies.

There are some reported promising results, but still far from the anti-icing level, durability and reliability required for use in aeronautical applications. In addition, there are no standard for the different required testing methodologies, complicating the search for solutions which meet aeronautical regulations.

During the PHOBIC2ICE European project several types of coatings, including metallic, ceramic and polymeric materials as well as composites applied by different coating deposition technologies where tested according to a common protocol designed by the project partners. Testing included ice accretion and adhesion of samples produced in laboratory scale icing tunnels, as well as in a large scale icing tunnel in which the coated specimens were rotated at high RPMs during the test.

The results of the diverse anti-icing strategies, using common testing methodologies, indicated some partial trends, but in all studied cases, the anti-icing behaviour is too low to be considered as an alternative to actual anti-icing aeronautic systems despite the high level of super-hydrophobicity exhibited by many samples.

These results, together with many others found in bibliography, raise questions about whether the development of proposed strategies could deal to useful results, or radical changes are needed to advance in real solutions.

TS1-5 Fluorination of Aluminum Surfaces as a General Strategy to Induce an Effective Anti-Icing Response,
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Icephobicity and anti-icing response of common materials used in aviation, such as Al6061, depends on different factors, such as surface morphology or chemical state. This work presents a systematic study of the wetting and anti-icing properties of aluminum surfaces that are modified by different procedures. Firstly, it is found that surface roughness modification by nanosecond pulsed IR laser treatments may induce a superhydrophobic behavior that also conveys an effective anti-icing response. An enhanced effect in wetting and anti-icing responses is observed for rough aluminum surfaces covered with porous Al_2O_3 layers providing a dual roughness surface microstructure. Then, we show that the anti-icing behavior can be highly improved by the surface functionalization of these aluminum surfaces with fluorine containing compounds or layers. The applied methodologies encompass the deposition of fluorinated polymeric coatings (CFx) prepared by plasma enhanced chemical vapor deposition, the infusion of a low surface tension slippery liquid (Krytox) or the surface grafting of fluorocarbon molecules (perfluorooctyltriethoxysilane, PFOTES).

A comparative analysis of the wetting, water condensation and anti-icing properties (freezing delay time and ice accretion in a wind tunnel) of these three fluorine modified surfaces have serve to determine the factors contributing to the observed good anti-icing performance and long term stability of metal fluorinated surfaces. This analysis takes into account the influence of roughness parameters, the chemical state of the surface and the mobile character of the fluorocarbon molecules to promote an efficient anti-icing response. A general methodology to develop fluorinated metal surfaces with an effective anti-icing behavior is proposed (1,2).

1.-V. Rico et al., Hydrophobicity, Freezing Delay, and Morphology of Laser-Treated Aluminum Surfaces, Langmuir 35 (2019) 6483–6491

2.- V. Rico et al., Robust anti-icing superhydrophobic aluminum alloy surfaces by grafting fluorocarbon molecular chains, Applied Materials Today 21 (2020) 100815

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