Topical Symposia
Room Royal Palm 1-3 - Session TS5
Anti- and De-icing Surface Engineering

Moderators: Alina Agüero Bruna, Instituto Nacional de Técnica Aeroespacial (INTA), Jolanta Klemberg-Sapieha, Polytechnique Montréal

1:30pm **TS5-1 Multi-step Modification of TI-Alloy and Stainless Steel Surfaces for Icephobic Applications***, **Stephen Brown**, J Lengaigne, A Riera, L Martinu, J Klemberg-Sapieha,* Polytechnique Montreal, Canada

In-flight component icing is a major issue in aerospace as it can lead to component failure or even cause aircraft to crash. While active solutions to icing such as heating and pneumatic boots do exist, a passive solution is desirable to avoid the additional weight and energy requirements of these systems. Superhydrophobic surfaces have been shown to reduce ice adhesion compared to bare metal surfaces; as such there is much interest in the modification of components to render them superhydrophobic.

In the present study, we look at a technique to modify the surfaces of Ti-6Al-4V and stainless steel substrates, to give them the hierarchical micro- and nano-scale roughness required for superhydrophobicity without invoking complex and costly processes such as photolithography. The desired morphology is obtained through a two-step process: samples are first sandblasted with alumina particles, and are subsequently etched in SF_6 plasma with a stainless-steel mesh placed directly on the sample to serve as a mask. The sandblast step induces a micro-scale roughness on the sample surface; the etching step adds more organized micro-scale features in the form of consistently sized and spaced pits, as well giving the surface nano-scale features. Mesh sizes as well as etching times are taken into consideration. Surface roughness remains relatively low after etching, with R_a < 5µm, and R_z < 30 µm. After coating with a fluorocarbon by thermal evaporation, the surfaces are rendered superhydrophobic with static water contact angles up to 170° and contact angle hysteresis as low as 6°.

1:50pm **TS5-2 Design and Characterization of Super-low Ice Adhesion Surfaces***, **Zhiliang Zhang**,* Norwegian University of Science and Technology (NTNU), Norway

Preventing the formation and accretion of ice on exposed surfaces is of great importance for Arctic operation, renewable energy, electrical transmission cables in air and shipping. While studies on suppressing ice nucleation by surface structuring and local confinement are highly desired, a realistic roadmap to icephobicity for many practical applications is perhaps to live with ice, but with the lowest possible ice adhesion. From the viewpoint of fracture mechanics, the key to lower ice adhesion is to maximize the ice-substrate interface-crack driving forces at multiple length scales. Herein, we present a novel macro-crack initiator mechanism in addition to the nano-crack and micro-crack initiator mechanisms, and demonstrate a new strategy to design super-low ice adhesion surfaces by introducing ordered sub-structures into smooth durable PDMS coatings to ultimately weaken ice-substrate interface [1]. Our results show that PDMS (weight ratio 10:10) thin films with 1 mm inner holes in two layers approach an ice adhesion strength of 5.7 kPa. The introduction of sub-structures into PDMS thin films promotes macro-crack initiators, and is able to further reduce ice adhesion strength by ~50% compared with that of PDMS thin films without sub-structures, regardless of layer thickness, curing temperature, weight ratio and the size of inner hole. Therefore, rationalizing the three crack-initiator mechanisms and their interactions at multi-length scales may provide an effective strategy towards designing super-low ice adhesion surfaces.

Reference:

[1] Zhiwei He, Senbo Xiao, Huajian Gao, Jianying He and Zhiliang Zhang, Multiscale crack initiator promoted super-low ice adhesion surfaces, *Soft Matter*, (2017) 13, 6562-6568.

2:10pm **TS5-3 Icephobic Nanocomposites for Aeronautics***, F Martín, **Silvia Larumbe**, M Monteserin, G Garcia Fuentes,* Asociación de Industria Navarra, Spain*; J Mora Nogues, P García Gallego, A Agüero Bruna, R Atienza,* INTA, Spain

Ice Protection Systems (IPS) are remarkable and essential parts of aircrafts since the formation of ice undergone in extremely hard conditions could give rise to the lack of the controllability of the aircraft. Traditional deicing systems suppose expensive and complicated systems that demand a very careful maintenance [1]. Moreover, the complexity of some of these systems makes them difficult to accommodate in small-medium aircraft. The need of seeking new systems with advantages like costs, low power consumption, reparability and lightness entails a relevant challenge.

In this regard, different coatings based on nanocomposites have been developed as passive systems against ice formation [2]. The basis of these coatings is the additivation of a hydrophobic matrix (silicones) with inorganic nanoparticles creating a controlled microroughness in the surface responsible of the icephobic behavior of the final coating. The main features to control during the process are on one side, the dispersion of the inorganic nanoparticles and on the second hand the final roughness. For the first aim, the inorganic particles were dispersed ultrasonically using high surface particles to improve the final dispersability in the organic matrix and also the final concentration was adjusted to obtain an enough microroughness for the accomplishment of a superhydrophobic coating keeping a good final adherence of the coating.

Several coatings based on nanocomposites with silicone and fluorosilicone reinforced with high surface alumina nanoparticles were prepared onto Al6061 substrates with different concentration of particles. The final adherence was optimized through different chemical and physical approaches obtaining as result a better adherence after the imprimation of the bare substrate and the subsequent use of an anchoring coating. The measurement of contact angle, roughness, ice formation, ice adherence and resistance to erosion were some of the characterization measurements carried out for the different coatings. Good adherence, contact angles within the range of 110-150° were obtained depending on the final additive concentration, improvement of the erosion resistance and lower ice formation comparing with other hydrophobic materials were some of the features of the developed materials, revealing these coatings as a promising alternative to other conventional IPS.

Acknowledgements

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References

F.T. Lynch et al, *Progress in Aerospace Sciences* **37,** 669 (2001).

H. Wang et al, *Applied Surface Science***349,** 724 (2015).

2:30pm **TS5-4 Development of Hydrophobic/icephobic Poly (Dimethylsiloxane) Based Composite Coating for Application in Ice Protection***, **Junpeng Liu**, J Wang,* University of Nottingham, UK*; H Memon,* University of nottingham, UK*; T Barman, B Turnbull, K Choi, X Hou,* University of Nottingham, UK

Accretion of ice on the surfaces of various engineering products under severe temperature condition is known to cause adverse socio-economic impacts and may lead to disasters. Development on hydrophobic/icephobic coatings has attracted increasing attention in many industrial areas, especially in aerospace. Aiming for reducing energy consumption for ice protection, poly(dimethylsiloxane) (PDMS) based composite coating had been developed. Particulate phase was integrated into the coating to improve the hydrophobicity and de-icing performance of the coating, and to reduce the overall energy consumption on ice protection. Ice adhesion tests were performed using a centrifuge method with a glaze ice block frozen on the studied coating in an environment chamber with temperature of -5 °C, with un-coated aluminium plates as references. The durability of the coatings was evaluated by erosion test under pressurized water droplet impinging. The composite coating demonstrated a typical water contact angle of 153° indicating good hydrophobicity. The ice adhesion test results showed an average ice adhesion strength of 5.8 kPa between the ice block and the coatings which is much lower than that of aluminium references (152.7 kPa). The de-icing test result indicated that PDMS-based composite coatings would effectively remove the ice and had great potential for application in ice protection.

Acknowledgement:

This work was supported by CleanSky II EU initiative GAINS (Grant Agreement No: 671398). The work forms a part of the project to develop a suitable hydrophobic and icephobic coating on aircraft wing surfaces.

2:50pm **TS5-5 Correlation Between Room Temperature Characteristics and Ice Adhesion***, **Jianying He,*** Norwegian University of Science and Technology (NTNU), Norway

Ice adhesion strength is dependent on the surface properties, and surface wettability is often correlated with ice adhesion strength. However, these established correlations are limited to high ice adhesion and become invalid when the ice adhesion strength is low. In this work we carried out an experimental study to explore the relationships between low ice adhesion strength and room temperature surface properties [1]. A variety of room temperature properties of hydrophilic and hydrophobic samples consisting of both low and high ice adhesion surfaces were analysed. The properties investigated include water adhesion force, water wettability, roughness, elastic modulus and hardness. Our results show that low ice adhesion strength does not correlate well with water contact angle and its variants, surface roughness and hardness. Low elastic modulus does not guarantee low ice adhesion though surfaces with low ice adhesion always show low elastic modulus. Low ice adhesion (below 60 kPa) of tested surfaces may be determinative of small water adhesion force (from 180 to 270 µN). Therefore, measurement of water adhesion force may provide an effective strategy for screening anti-icing or icephobic surfaces, and surfaces within specific values of water adhesion force will possibly lead to a low ice adhesion.

Reference:

[1] Zhiwei He, Elisabeth T. Vågenes, Chrisrosemarie Delabahan, Jianying He & Zhiliang Zhang, Room Temperature Characteristics of Polymer-Based Low Ice Adhesion Surfaces, *Scientific Reports* (2017) 7:42181.

3:10pm **TS5-6 Impact Dynamics and Icing Behavior of Supercooled Water Microdroplets on Surfaces of Different Wettabilities Ranging from Superhydrophilic to Superhydrophobic***, **Jacques Lengaigne,*** Polytechnique Montreal, Canada*; E Bousser,* Polytechnique Montreal, UK*; A Riera,* Polytechnique Montreal, Canada*; D Batory,* Lodz University of Technology, Poland*; S Brown,* Polytechnique Montreal, Canada*; A Dolatabadi,* Concordia University, Canada*; L Martinu, J Klemberg-Sapieha,* Polytechnique Montreal, Canada

Atmospheric icing on aircraft is a significant danger during flight and leads to high additional costs for operators. Icing occurs when supercooled micrometric water droplets (SWD), impact surfaces and freeze. Icephobic coatings based on superhydrophobic surfaces are the most promising avenue to replace current energy intensive techniques such as heaters and de-icing fluids. However, their wetting behavior under SWD icing is not well explored.

In this work, we investigate the influence of wettability on the impact dynamics of supercooled microdroplets. Four surface types with different wettabilities (characterized by their water contact angle, θ) were studied: superhydrophilic θ=10°, hydrophilic θ=70°, hydrophobic θ=107° and superhydrophobic θ=173° . Realistic atmospheric conditions, leading to supercooled microdroplet freezing, were simulated in an icing wind-tunnel with a wind speed of 10 m/s, subzero temperatures (down to minus 18° C) and a mean droplet diameter of 40 µm. High speed imaging was used to capture the impact sequence of droplets on the different surfaces.

Impact dynamics show transition from wetting to bouncing when the surface becomes hydrophobic. However, in icing conditions the repelling behavior is only maintained for the superhydrophobic coating whereas droplets freeze on the other surfaces. Limitations of superhydrophobic coatings under SWD icing are also explored.

3:30pm **TS5-7 Quasicrytalline Coatings by HVOF to Improve the Ice Accretion and Durability in Aerostructures Components***, R Muelas Gamo,* ***Julio Mora Nogues****, P García Gallego, A Agüero Bruna,* Instituto Nacional de Técnica Aeroespacial (INTA), Spain

Weather hazards, in particular icing conditions, are an important contributing factor in aviation accidents and incidents world-wide. Further advancements in mitigation of in-flight performance degradation are necessary. This problem is being studied following two strategies: active systems or de-icing once the ice has formed, and passive or anti-icing systems to prevent or retard accretion. Many different anti-icing strategies are currently being explored to find suitable long-lasting solutions such as surface engineering which can provide a better alternative by reducing or eliminating ice accumulation.

Quasicrystals (QCs) are metallic materials in nature but with similar properties to those of ceramic materials, such as low thermal and electrical conductivities, and high hardness. These materials exhibit five and seven fold rotational symmetries, which were forbidden according to the rules of classical crystallography. In particular, those that have low surface energy are good candidates to be employed as icephobic coatings. These types of coatings are used commercially instead of Teflon on frying pans as they do not scratch easily.

Al based QCs have been applied by High Velocity Oxyfuel (HVOF) thermal spray on typically used aeronautic materials such as Ti and Al alloys as well as steels. The coatings have been characterized and evaluated (adhesion, hardness, wetting angle and ice accretion in an Icing Wind Tunnel. Moreover surface modifications of the coating have been carried out by laser and machining in order to study the effect of the surface roughness and morphology on the ice accretion properties. The QC coating has been compared with an anti-icing commercial paint, and the result indicate a significant reduction of the ice accretion behaviour. Since the coatings are hard ($HV_{0.3}$: 550), a durable behaviour is expected.

The proposed solution is and will help eliminate the need for frequent on-ground de-icing procedures. This in turn will contribute to the reduction of cost, pollution and flight delay.

Author Index

Bold page numbers indicate presenter