

Editorial

## Special Issue “Anti-Icing Coatings and Surfaces”

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It is a known fact that ice adheres to any surface and strongly. Unfortunately, this strong adhesion is not the strongest quality any industry would look forward to. The strong adhesion only causes damage, material-wise, as well as to people’s lives. Ice adheres to surfaces of structures such as aircraft parts, streets and sidewalks, automobile windshields, conducting cables and insulator surfaces, posing major inconvenience or even a significant danger challenging public safety, as well as industry operations. For instance, formation and accumulation of ice on aircraft structures, such as their wings, hinders the functionality of parts such as sensors, resulting in unprecedented crashes causing serious injuries and even the deaths of passengers and aircraft crews. The Continental commuter flight 3407 crash in February 2009, which claimed 50 lives due to ice on the wings and cockpit windshields, is one such tragic example. Another major event, “The Great Ice Storm” of January 1998, deprived millions of Quebec and Ontario residents of electricity for up to several weeks to months after collapsing many power lines and more than 1000 pylons (just like dominos), causing 34 fatalities due to reasons related to power outages and leading to billions of dollars in damages [1]. The ice build-up on the cables and high-tension lines was the major culprit. Similarly, the December 2005 winter storm in the southern United States resulted in major power outages and at least seven deaths. Thick ice and snow build-up on trees and cables caused most damages. There has been many more such winter classic catastrophes caused by ice formation and build-up on the surfaces of various structures, which has been briefly mentioned in the introductory sections of the articles in this Special Issue.

The problems related to ice adhesion on structures is a global annoyance which has caused and is still causing threat to industry and public safety in many parts of the world, including North American (USA, Canada), Asian (Japan, China) European and Scandinavian countries, as reflected by the research contributions in this Special Issue by authors from these countries who constantly strive to minimize its impacts [1–10]. World renowned experts have been addressing the ice adhesion issues with their advanced research and development and in the finding of advanced technologies to evaluate the adhesion phenomena, both theoretically and experimentally.

One of the most significant approaches to address the ice adhesion issues is to possibly eliminate the adhesion of ice itself to the surfaces in the first place, since removing adhered ice is not an easy task. Mechanical, chemical and thermal de-icing techniques are, respectively, destructive, environmentally unfriendly and highly energy-demanding, in addition to the disadvantage of very high cost involved. These techniques are useful only on surfaces on which there is already accreted ice. So, how to eliminate adhesion of ice on the surface is the major challenge. Much research has focussed on coatings with the ability to repel water and, therefore, ice, as ice is essentially water in its chemical form. If a surface can be made to repel water, it is expected that the ice will not stick to that surface or will have lowest adhesion (lower water contact points), making it easier to shed off just by slight external force. Such coatings, called superhydrophobic or anti-icing coatings or icephobic coatings, pose another challenge in terms of long-term durability. Although



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investigations in this field of research around the world have been carried out for decades, the literature is still relatively scarce in this field.

This Special Issue provides a forum for the basic aspects, theories and mechanisms of adhesion and surface science in general, and deals with applications in all areas of technology. The impact of novel coatings on ice adhesion strengths based on the coating formulations and methods, as well as the ice adhesion performance evaluation techniques to evaluate the coatings with ice formed on them at sub-zero temperatures are covered. The ten contributions constituting this Special Issue are composed of the latest developments and the state of the art regarding ice adhesion, which are well elaborated for a wide range of readers, including research scientists, students and industrials, as well as the curious audience. These ten contributions originate from countries worldwide, namely, Canada (Quebec), Italy, Spain, China, Norway, Germany, Bulgaria and USA [1–10].

The contribution by authors Saleema Noormohammed and Dilip Kumar Sarkar from Quebec, Canada, titled “Rf-Sputtered Teflon<sup>®</sup>-Modified Superhydrophobic Nanostructured Titanium Dioxide Coating on Aluminum Alloy for Icephobic Applications” demonstrates promising ice adhesion reduction, almost negligible, onto aluminum surfaces coated with dielectric materials modified by radio-frequency sputtered Teflon<sup>®</sup> for application on insulators, as well as on cables surfaces [1]. The method these authors used was inspired by the one presented by Sigrid Rønneberg et al.: the centrifugal ice adhesion test (CAT), developed by AMIL-LIMA group of the University of Quebec at Chicoutimi (UQAC) [7]. These authors’ contribution, titled “Interlaboratory Study of Ice Adhesion Using Different Techniques”, however, provides an insight on testing methods by comparing two different methods, namely, the CAT and the vertical shear adhesion test, on precipitation ice and bulk water ice [7]. They performed the adhesion tests at two different temperatures:  $-10\text{ }^{\circ}\text{C}$  and  $-18\text{ }^{\circ}\text{C}$ . The results and analysis reported by these authors provide insight on the dependence of ice adhesion strengths on the various conditions and test methods used. The work, however, involves testing and comparing bare aluminum surface and aluminum surface coated with commercial icephobic coating, emphasizing the effect of the coating on ice adhesion strengths.

The article titled “Different Approaches to Low-Wettable Materials for Freezing Environments: Design, Performance and Durability” by Giulio Boveri et al. presents a highly interesting observation on wettability behavior at sub-zero temperatures ranging from 0 and  $-10\text{ }^{\circ}\text{C}$  and the stability of wettability in the said range on their lotus-leaf like metal surfaces [2]. The ability of their surfaces in maintaining their low wetting behavior during the freeze and frost/thaw durability cycles shows promise for large-scale developments for industrial uses.

The paper titled “Evaluation of Functionalized Coatings for the Prevention of Ice Accretion by Using Icing Wind Tunnel Tests” by Pedro J. Rivero et al. presents an interesting approach to fabricating anti-icing coatings using chemical methods including sol-gel, advanced paints based on polyester combined with fluorinated derivatives applied onto metal surfaces by electrostatic spray deposition [3]. Their coatings’ evaluation upon ice accretion using the double lap shear test (DLST) proved to be durable even after 25 icing/de-icing cycles, again showing promise for large-scale manufacturing.

The editor’s choice, titled “Hard Quasicrystalline Coatings Deposited by HVOF Thermal Spray to Reduce Ice Accretion in Aero-Structures Components” by J. Mora et al., presents the fabrication of durable hard quasicrystalline coatings with the aim of replacing Teflon<sup>®</sup> as anti-icing coatings [4]. This work presents the deposition of Al-based coatings using the high-velocity oxy fuel technique on Al and Ti alloys surfaces. The HVOF method results in ceramic-like hard coatings, which can lead to excellent durability following several icing/de-icing cycles.

Various other interesting coating approaches, new coatings types and ice adhesion evaluation on ice accreted coatings have been elaborated in the papers named “A Novel Simple Anti-Ice Aluminum Coating: Synthesis and In-Lab Comparison with a Superhydrophobic Hierarchical Surface” by Marcella Balordi et al. [5], “Anti-Icing Performance of

a Coating Based on Nano/Microsilica Particle-Filled Amino-Terminated PDMS-Modified Epoxy” by Qiang Xie et al. [6], “Reversible Switching of Icing Properties on Pyroelectric Polyvinylidene Fluoride Thin Film Coatings” by Dirk Spitzner et al. [8] and “From Extremely Water-Repellent Coatings to Passive Icing Protection—Principles, Limitations and Innovative Application Aspects” by Karekin D. Esmeryan [9]. The contribution from Karekin D. Esmeryan provides an excellent review and state-of-the-art on the various aspects of ice adhesion studies, including coatings, their limitations in icephobic applications and novel hybrid anti-icing systems [9].

The commentary contribution titled “On Modulating Interfacial Structure towards Improved Anti-Icing Performance” by Kshitij C. Jha et al. highlights the role of interfacial water structure, a very fundamental physico-chemical aspect of ice accretion, on ice adhesion emphasizing hydrogen bonding, as well as the role of the chemical elements/ions from their chemically modified surface [10]. Interfacial phenomena are of significant importance in the adhesion of ice to surfaces as it is the interfacial forces and bonds which eventually control the adherence of ice to the surface. Understanding the interface is, therefore, of significant importance and this contribution is an effort to address these phenomena.

In summary, this Special Issue addresses the long-lasting challenge of the strong adhesion of ice to surfaces of structures, costing industries large amounts in damages and causing threat to public safety during extreme winter conditions in cold countries. Global warming only worsens these conditions, making it more challenging and urgent in tackling the challenges in smart ways. The contributions in this Special Issue from world renowned experts directly address the important aspects in facing these challenges and resolving these issues by the formulation and application of new generation coatings, elaborating theoretical aspects on the coatings’ chemical and morphological characteristics, impacting ice adhesion strengths, and by using efficient ice adhesion evaluation techniques for the performance and durability of the novel coatings. The Special Issue would be of significant benefit for anyone who works in this field, as well as to those interested in general learning in the field.

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