Breaking the ice using passive anti-icing coatings – Lessons learned from the Nordic TopNANO research project

Presented by Agne Swerin, SP Technical Research Institute of Sweden
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TopNANO – ice accretion related to wind, airplanes and heat exchangers

• Need and potential for nanotechnology to increase energy efficiency and combat icing problems
• Description of TopNANO project – Nordic Top-level Research Initiative for applied nanotech
• Summary of project outcome
  – Superhydrophobicity – when it works and does not work for anti-icing
  – Ice adhesion on substrates with quasi-liquid layers
  – Methodology for studies of biological stain removal
  – Icing wind tunnel and new ice adhesion test
  – Scaled-up field tests at a wind park
  – Nordic platform for ice-related research and innovation
Co-authors to this presentation

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Project and funding partners

- Research partners in surface chemistry, coatings and ice physics
Project and funding partners

• Companies from aircraft, wind power, heat-exchanger industry and coating companies
Ice and frost formation – a nanotech area?

• Ice exists in fifteen different forms, the most usual is hexagonal
• Frost is formed directly from water vapor
• Ice is a nanostructured material
• Methodology to combat ice build-up is nanotechnology
Icing – a complex problem

Different types of icing depending on the conditions

- **In-cloud icing**
  - Supercooled water droplets
  - Soft rime, hard rime, glaze

- **Precipitation**
  - Snow or rain
  - Freezing rain
  - Wet snow

- **Frost**
  - Water vapor solidifies on a cool surface
Anti-icing and de-icing

De-icing: removal of ice
Anti-icing: prevention of ice accretion

- **Active**
  - Mechanical (de-icing)
  - Thermal (heating foils or hot air)

- **Passive**
  - Chemical
  - Surface coatings

• Thermal requires lots of energy and chemicals may be harmful for the environment
• Anti-icing coatings the ideal solution
• But... few commercial products available
Deliverables

• Optimization of **surface chemistry and surface topography on the nanometer scale** to retard ice and condensation formation

• Effect of different **surface anchored functional groups**, polar uncharged and polar charged groups, on ice adhesion

• Develop **robust superhydrophobic** coating formulations
Deliverables, cont’d

• Negative influence of **biological fluid stains** from impacted insects on wind turbines, aircraft wings and heat exchanger surfaces

• Novel **nanotech coatings for anti-freezing**

• New surface materials and **benchmarking** against the existing technology, in terms of cost, performance and LCA
Deliverables, cont’d

• **Shorter and longer field tests** during the winter seasons
• Transfer to Nordic industries through direct industry-academia collaborations
• **Develop Nordic platform for deicing and anti-icing and proliferate to other sectors**
• Industry partners at the end of the project have one concept validated under relevant conditions, two more validated in lab and another three concepts tested
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Lead ideas to reduce ice formation

• Superhydrophobic surfaces
• Surfaces exposing chemical groups that are water-structure breakers
• Understand on a molecular level *why* or *why not* these concepts work
The superhydrophobic track

- Preparation of superhydrophobic coatings
- Surface energy recovery after soiling
- Depends on the *receding* contact angle
  - Soiling a major issue
- Superhydrophobicity relies on surface chemistry and *topography*
  - Wear resistance crucial

\[ W_{adh} = \gamma_{LV} \left( 1 + \cos \theta_{rec} \right) \]
Does a superhydrophobic surface retard droplet freezing?

- Surfaces with similar chemistry but different topography
- Water contact angles as function of temperature
- Water droplet freezing delay time
- Results explained by heterogeneous nucleation theory
Contact angle as a function of temperature

Water condensation and frost formation reduces contact angles on the superhydrophobic surface

Conclusion

- Contact angles measured at room temperature do not represent the wetting under supercooled conditions
Freezing delay on different surfaces

- No benefit from a superhydrophobic surface, if anything a smooth surface is better!

Heidari et al. (2010)
SP Technical Research Institute of Sweden
The explanation – heterogeneous nucleation

- Large surface features should not have any effect since $r^*$ is small
- All real surface has both concave and convex features
- Freezing occurs most readily in depressions (concave) and least readily on concave sites

Increasing energy barrier for ice nucleation

$X = \frac{r}{r^*}$

- $r$ = radius of surface feature
- $r^*$ = critical ice nucleation radius ≈ 9 nm at -5 °C and about 4.5 nm at -10 °C
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Anti-icing coating

- Quasi liquid layer
- Hydrophilic polymers at the solid surface
- How does different ions influence ice adhesion?
Ice adhesion measurements

Freezing set up

- Cuvette
- Cantilever
- Force Sensor
- Substrate
- Movable platform
- Inverted lab jack
- Freezer
- Peltier

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Top-level Research Initiative
• Ice adhesion with counterion Li$^+$
  – 40 % lower at -18 °C
  – 70 % lower at -10 °C
  – Different type of failure

*Chernyy et al. (2014), ACS Appl Mater & Interf*
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Wind power – Field tests in two winters 2013 and 2014

• Surface modification of samples
• Surface characterization
• Mounting samples and monitoring
• Evaluation of samples post-winter
Work flow

Coating development

In collaboration with companies

Characterization on the lab scale

Both coatings developed within the project and commercially available

Field tests

Subgroup wind/aircraft

At Vattenfall’s wind power plant in Northern Sweden

Subgroup Heat exchanger

Tests at industrial partners’ labs

TOP NANO
Best candidates from laboratory ice adhesion tests

![Ice Adhesion Test](image)

- Top NANO
- SP Technical Research Institute of Sweden
- Norden
- Top-level Research Initiative
Field tests at Vattenfall’s wind power plant in Northern Sweden during two winters
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Superhydrophobic coating #2

Snapshots from water wetting experiments before and after field tests

Before field tests – water runs off
Field tests at Vattenfall’s wind power plant in Northern Sweden during two winters

Superhydrophobic coating #2
Snapshots from water wetting experiments before and after field tests

Same sample after field tests – still good
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Example of related projects

- ANTIS – Norwegian research council
  - Passive anti-icing coatings
- Micro-Deice – Swedish Energy agency
  - Active anti-icing
- Retrofit-Deice – KIC Innoenergy
  - Active anti-icing
- ICECONTROL – Eurostars
  - Anti-icing control on railroads
TopNANO – project summary

Main achievements

• Well-functioning consortium and research collaboration in the Nordic countries
• Strong engagement from industry: advice, samples/testing, field tests
TopNANO – project summary

Crucial elements for project success

• Strong industrial participation in project group
• Field tests and scaled-up tests for wind and heat exchanger applications
TopNANO – project summary

Take aways

• Established Nordic platform
• Broaden to other sectors (maritime, off-shore, transport, power transmission, etc.)
• Major public funding and industrial contracts
• Work through the network of TopNANO industrial companies.