ANTI-ICING COATINGS AND DE-ICING
TECHNICAL APPROACHES AND STATUS

Dr. Stephan Sell
B. Sc. Andreas Stake, Mathias Widrat, Volker Föste,
Dr. Volkmar Stenzel
Fraunhofer IFAM, Germany

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Content

• Introduction: General anti-ice aspects
• Evaluation of anti-ice coatings at Fraunhofer IFAM
  • Ice formation tests
  • Ice adhesion tests
  • Tests under real conditions
• Development of Anti-ice and De-Icing coatings technologies at Fraunhofer IFAM
  • Active coating concepts
  • Passive coating concepts
  • Electrically heated coating concepts
• Outlook
General anti-ice aspects

Anti-ice and de-icing coating concepts are relevant for varying technical fields:

Means of transportation (aircrafts, cars, trains and ships)

Wind energy plants,

Solar energy plants,

Heat exchangers

Effective Anti-ice and de-icing coatings help to

• reduce costs and energy consumption
• enhance product value
• improve performance of technical goods
• contribute to safety concerns
General anti-ice aspects

Determining factors for the development of effective anti-ice coatings:

| Icing conditions for the specific technical application  
| e.g. Aeronautical Applications, Automotive Industry, Wind energy plants |
| Further technical requirements on the coating  
| e.g. Rain, Sand, and Ice Particle Erosion, anti-soiling (insect debris) |

Tailor-made coatings for respective technical application

To achieve this you will need:

- Ice test facilities
  - taking into account relevant icing conditions,
  - that are able to discriminate between new designed coatings regarding ice prevention or reduction,
  - cover a broad range of ice tests to avoid misinterpretation
IFAM ground ice-tests facilities (and access to testing)

IFAM ice chamber

Ice adhesion tests

tests under real conditions

ice rain, rime and runback-ice tests
Ice formation tests

IFAM ice chamber for evaluation of anti-ice coatings:

- Maximum wind speed of 45 m/sec
- Rain application via nozzle
- Visual inspection via web cam
- Air temperatures down to -10°C
- Substrate temperatures down to -40°C
- Relative humidity down to 60% at -10°C
Ice formation tests

Conventional approach for anti-icing: Hydrophobicity

IFAM ice chamber tests: standard test scenarios

Ice rain test: Simulates run-off behaviour of water and subsequent formation of clear ice

Rime test: Simulates the formation of rime
Ice formation tests

Rime test
Simulates formation of rime

Ice rain test
Simulates run-off behaviour of water and subsequent formation of clear ice

<table>
<thead>
<tr>
<th>Test conditions</th>
<th>Test conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>Air temperature</td>
</tr>
<tr>
<td>+1°C</td>
<td>-5°C</td>
</tr>
<tr>
<td>-2°C</td>
<td>down to -5°C</td>
</tr>
<tr>
<td>88%</td>
<td>66%</td>
</tr>
<tr>
<td>9 m/sec</td>
<td>9 m/sec</td>
</tr>
<tr>
<td>rime thickness</td>
<td>10 seconds</td>
</tr>
<tr>
<td>and adhesion</td>
<td>visual inspection 10 min</td>
</tr>
<tr>
<td></td>
<td>after raining</td>
</tr>
</tbody>
</table>

Test conditions:
- Air temperature
- Substrate temperature
- Relative humidity
- Wind speed
- Rain duration
- Assessment
Ice adhesion tests

• **Pendulum test:**
  - ice cubes on test surface are knocked off by a pendulum
  - reduced energy of the pendulum is correlated to the adhesive strength of the clear ice, measured as angle of the pendulum amplitude

• **Centrifuge test:**
  - ice on test surfaces are removed by centrifugal force
  - piezo electric cells detect the impact of the detached ice layers
Ice adhesion testing: extract of results of rotor copter test

→ Up to now anti-ice coatings (2K PUR, Plasma) could be observed with low shear stress in comparison to Aluminium (Reference)
Tests under real conditions

Long-term ice tests on the Mt. Brocken (height: 1141,1m)

Results
• up to now all surfaces with ice formations under these harsh conditions
• ice adherence differs, depending on material
Anti-ice coating concepts

Fraunhofer IFAM works on concepts

- Prevent or reduce ice formations (Anti-ice)
- Reduce ice adhesion (improved De-icing)

with emphasis on highlighted methods:

**Active methods**
- Thermal
- Chemical
- Biochemical
- Mechanical

**Passive methods**
- Ice adhesion reduction
- Change of wetting behaviour

Combination of thermal and passive methods could reduced energy consumption up to 80%
Development and Evaluation of anti-ice functional surfaces and coating concepts

**Generell technological approaches for Anti-ice coatings work at IFAM**

- micro/nano-structured coatings (via particles) inorganic/organic
- Sol-Gel coatings (hydrophobe)
- passive coating concepts
- interfacial structuring (UV-process, photolithography)
- hydrophilic/hydrophobic coatings

**Performance**  **Availability**  **Applicability**  **Requirements**

**Selection of appropriate technologies**
**Active coating concepts**

**Chemical approach**

Further efforts are made within a BMBF funded project “New functional and biomimetical surfaces for the reduction of ice formation” 01RI0710B in cooperation with “Leibniz-Institut für Polymerforschung Dresden e.V.”

In this project, a polymer route was investigated Coblock polymers (PEG, - NHR) in the polymer matrix and one

-> Paint formulation route (2 K PUR, Sol-gel, UV curable coatings) and their influence on the anti-ice determines properties.

-> Master thesis by Tobias Ehlers:
Subject of UV curable transparent coatings for PMMA
### Ice grade Table

<table>
<thead>
<tr>
<th>Ice grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 / Ice-free</td>
<td>(Pictures show sample surfaces before sprinkling)</td>
</tr>
<tr>
<td>1 / Nearly ice-free</td>
<td>Only a few, relatively small water droplets on the surface.</td>
</tr>
<tr>
<td>2 / Isolated ice droplets</td>
<td>Small to medium sized droplets – most part of surface is ice-free.</td>
</tr>
<tr>
<td>3 / Moderate ice formation</td>
<td>Ice droplets relatively evenly distributed, but also ice free areas present.</td>
</tr>
<tr>
<td>4 / Enhanced ice formation</td>
<td>Most part of surface is covered by ice.</td>
</tr>
<tr>
<td>5 / Extensive and (nearly) complete ice coverage</td>
<td>respectively.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Photo 10 min after rain ice formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>VG-0</td>
</tr>
</tbody>
</table>
Investigations on the influence of key parameters on the icing behaviour

of transparent nano composite coatings for plastic surfaces (PMMA): Optimal balance of hydrophobicity, low surface energy and transparent scratch resistant surface were achieved with Perfluoropolyether (PFPE) and amorphous Silicate-nano (SiO\textsubscript{2}) particel modified coatings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unmodified PMMA</th>
<th>Passive transparent anti-ice coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water contact angle [°]</td>
<td>80</td>
<td>115</td>
</tr>
<tr>
<td>Surface energy $\sigma$ [mN/m]</td>
<td>42.0 ($\sigma_d$=38.0; $\sigma_p$ =3.4)</td>
<td>11.2 ($\sigma_d$=10.6; $\sigma_p$ =0.4)</td>
</tr>
</tbody>
</table>

Pictures of the Clear ice test (left) and Rime ice test (right)

Description of results

Clear ice formation

Clear Ice formation after 10 min at -5°C Ice grade 4

Reduced ice formation due to improved water run-off Ice grade 2

Rime ice formation

Rime Ice formation after 20 min at -5 °C Rime thickness 1000 µm

Rime Ice formation after 20 min at -5 °C Rime thickness 400 µm
Active coating concepts

**Biochemical (biomimetic) approach**

Work performed by Fraunhofer IFAM:
- relevant protein sequences were synthesized via Merrifield synthesis techniques
- most promising strategy identified: covalent linkage with use of additional linker molecules

- First promising results with reduced rime ice formation in ice chamber tests:

  - Temperature sensor
  - Coating film without AFP with a layer of ice of 525 +/-25 µm thickness
  - AFP-coating with a layer of ice of 425 +/- 25 µm thickness
Passive coating concepts

**Ice adhesion reduction and wetting minimisation**

Key parameters to be considered:

- **Types of bonding**
  - Electrostatic Interactions
  - hydrogen bonding
  - Van-der-Waals interactions

- **Hydrophobic character**
  - (super) hydrophobic coatings with reduced wetting behavior
  - reduced clear ice

- **Surface roughness**
  - influences hydrophobicity e.g. Lotus effect
  - influence ice adhesion

**Passive Anti-ice technologies**
Passive coating concepts

Investigations on the influence of key parameters on the icing behaviour of surfaces:

- Optimal balance of hydrophobicity, roughness and available bonding types at the surface were achieved with Fluor- and silicone-modified coatings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unmodified top coat</th>
<th>Passive anti-ice coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water contact angle [°]</td>
<td>82</td>
<td>124</td>
</tr>
<tr>
<td>Roughness Ra [µm]</td>
<td>0.17 (±0.01)</td>
<td>0.64 (±0.07)</td>
</tr>
<tr>
<td>Pictures of the ice rain test</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>
| Description of result               | Ice formation after rain at -5°C | • Reduced ice formation due to improved water run-off  
|                                    |                     | • Ice adhesion reduced |
| Limitation                          | Rime ice accretion is not reduced |
Technical demands on the coating „JTI project Clean Sky“

Low drag aircraft - Requirements

Surface

Erosion resistance

Anti-contamination

Anti-ice

United states NAVI trainings film
Ice Formation On Aircraft (1961)
Description of the work on anti-icing and surfaces

IFAM ice chamber for evaluation of anti-ice coatings: runback ice behaviour

Laser sinter process for the aerodynamic wing design (NACA 0020)

- Maximum wind speed of 45 m/sec
- Rain application via nozzle
- Visual inspection via web cam
- Visual inspection via FTIR cam
- Air temperatures down to -10°C
- Substrate temperatures down to -40°C
- Relative humidity down to 60% at -10°C

Runback ice formation

- Wind speed of 30 m/sec
- Relative humidity 66% at -5°C
- Warming in front +20°C and cooling behind the leading edge (-30°C) 20 min
- Application of water nozzles 1 min

Development of test design with wing profile to

- Simulate ice accretion on leading edge and
- Subsequent melting of ice, including runback ice formation
Investigation in electrically heated coatings

Carbo e-Therm (Future Carbon) on curved surfaces (e.g. Alu)

Electrically heated coating for use in the nonhazardous low-voltage range (e.g. 12/24V). Carbo e-Therm is suitable for temperatures up to approx. 160°C. It is using carbon nanotubes and graphite, a thin layer of electrically conductive material.

Melting the ice (Left: Infrared camera Right: live picture).

Spray applicability to curved geometries and surfaces.
Passive heatable functional surfaces

Heatable coatings (de-icing) in combination with chemical approaches (anti-icing)

International project (EU) JEDI ACE

Investigation in heating coatings
max. wind speed 45 m/s
1.) rain ice formation
2.) active heating

Targetests:
• Improved aircraft safety
• reduced energy consumption

<table>
<thead>
<tr>
<th>Resistance [Ω]</th>
<th>Type of coating / heating layer</th>
<th>Time de-icing -10 C -&gt; 5 C [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>Al 2024 Plated with coatable foil</td>
<td>Carbo e-Therm</td>
</tr>
</tbody>
</table>
Conclusion

- Icing tests covering different icing scenarios are available
- Tests for measuring ice-adhesion and rime-adhesion are available
- Analytical methods for the assessment of icing parameters are investigated
- Different approaches for the development of effective anti-icing and de-icing coatings are under investigation including:
  - Hydrophobic coatings for ice-rain protection
  - Heatable coatings in combination with hydrophobic coatings

Our next steps are:

• further research on the development of new coating concepts
• use of available knowledge to the needs of specific technical applications
• studies on further scientific background regarding icing processes
• further development of test methods to assure best prediction models
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Paint Technology
Fraunhofer Institute IFAM
Adhesive Bonding Technology and Surfaces
Dr. Stephan Sell
Wienerstraße 12

28359 Bremen

Tel: +49 421 2246-673
Fax: +49 421 2246-430
Email: Stephan.Sell@ifam.fraunhofer.de