# Recent Ice-related Test Results and Correlations with Surface Characteristics

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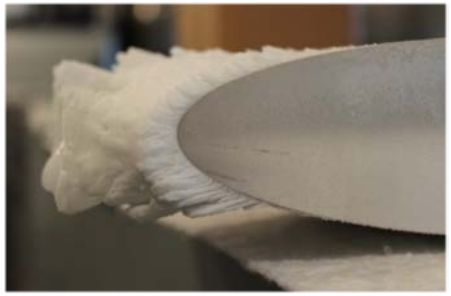

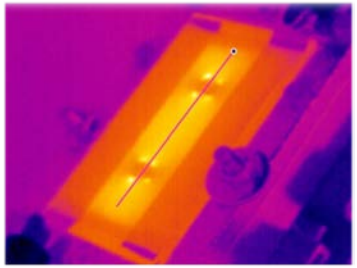



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- Overview:

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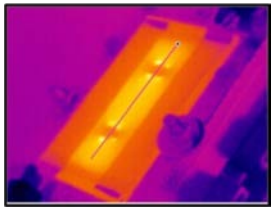
  vs.
  Surface characteristics
  vs.
  Field experience
  vs.
  Ice wind tunnel tests

- Conclusions and Outlook





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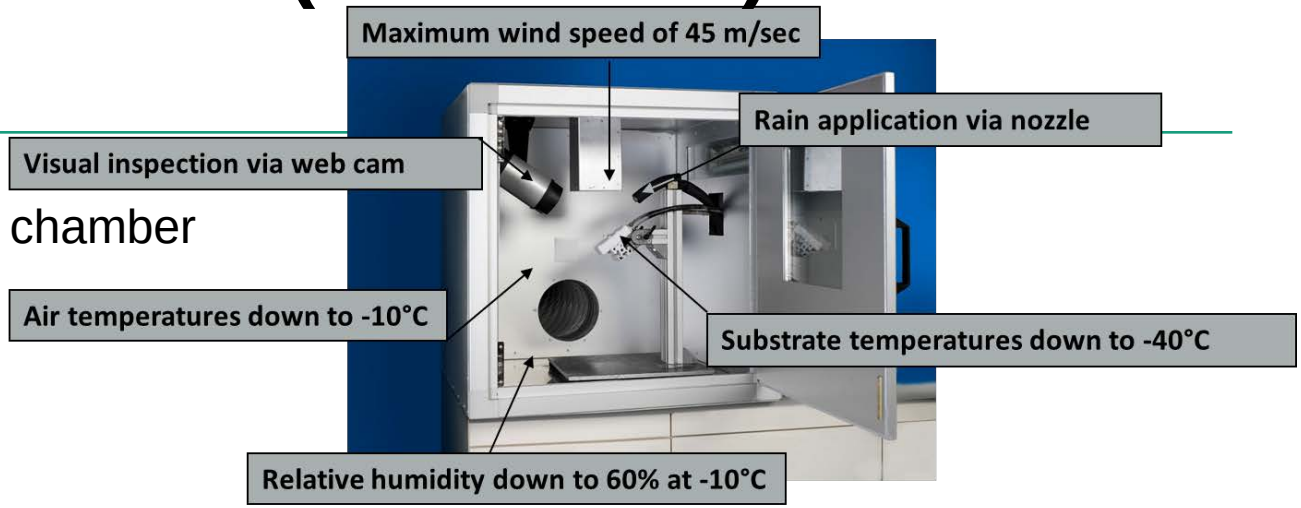
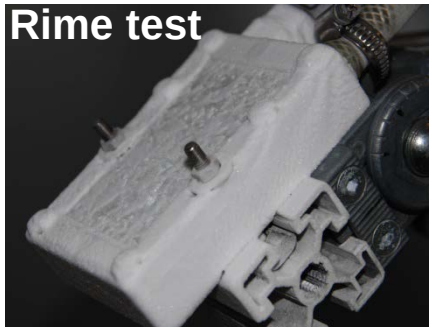
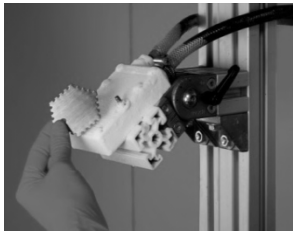
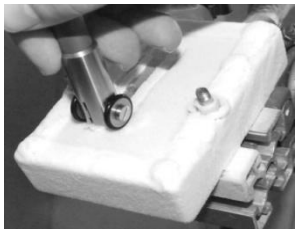
# Ice formation tests (Lab-based)

- Standard IFAM icing chamber

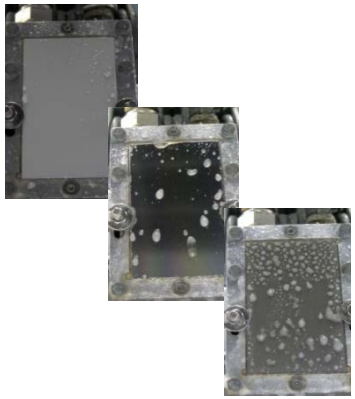




Simulates formation and adhesion of rime

Simulates water run-off and subsequent formation of clear ice



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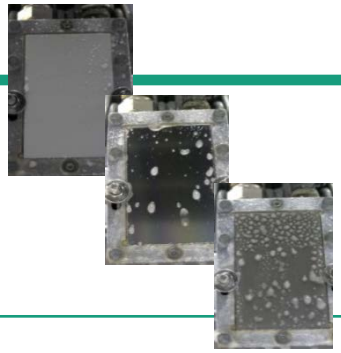
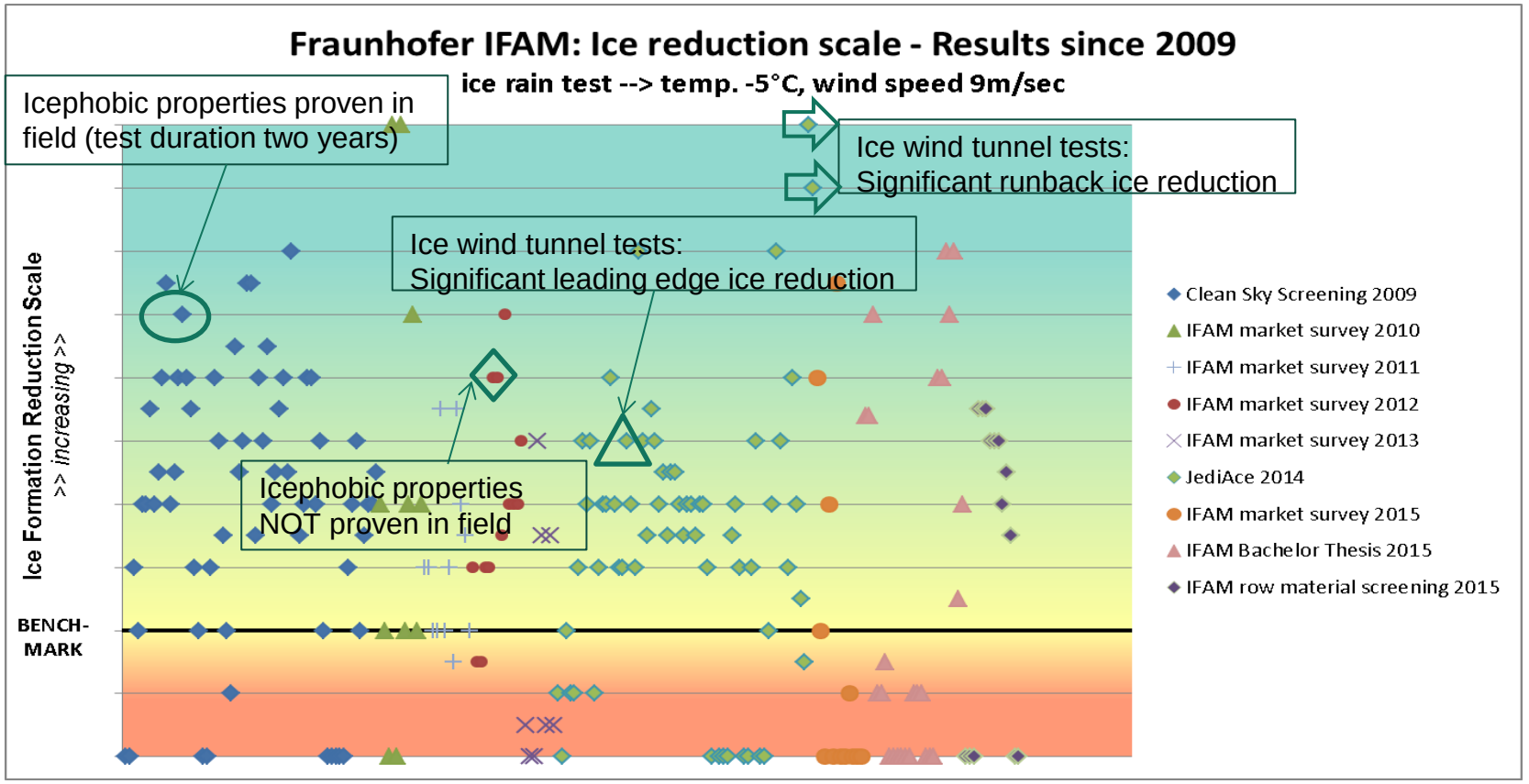
# Ice formation tests (Lab-based)

- One Example:

| Parameter | Unmodified PUR | F-modified PUR coating |
|---|---|---|
| Water contact angle [°]<br>Roughness Ra [µm] | 82<br>0.17 (±0.01) | 124<br>0.64 (±0.07) |
| Ice formation at -5°C in IFAM ice rain test |  |  |
| Ice adhesion | Significant ice adhesion reduction | |
| Limitation | Rime ice accretion is not prevented | |

# Ice formation tests



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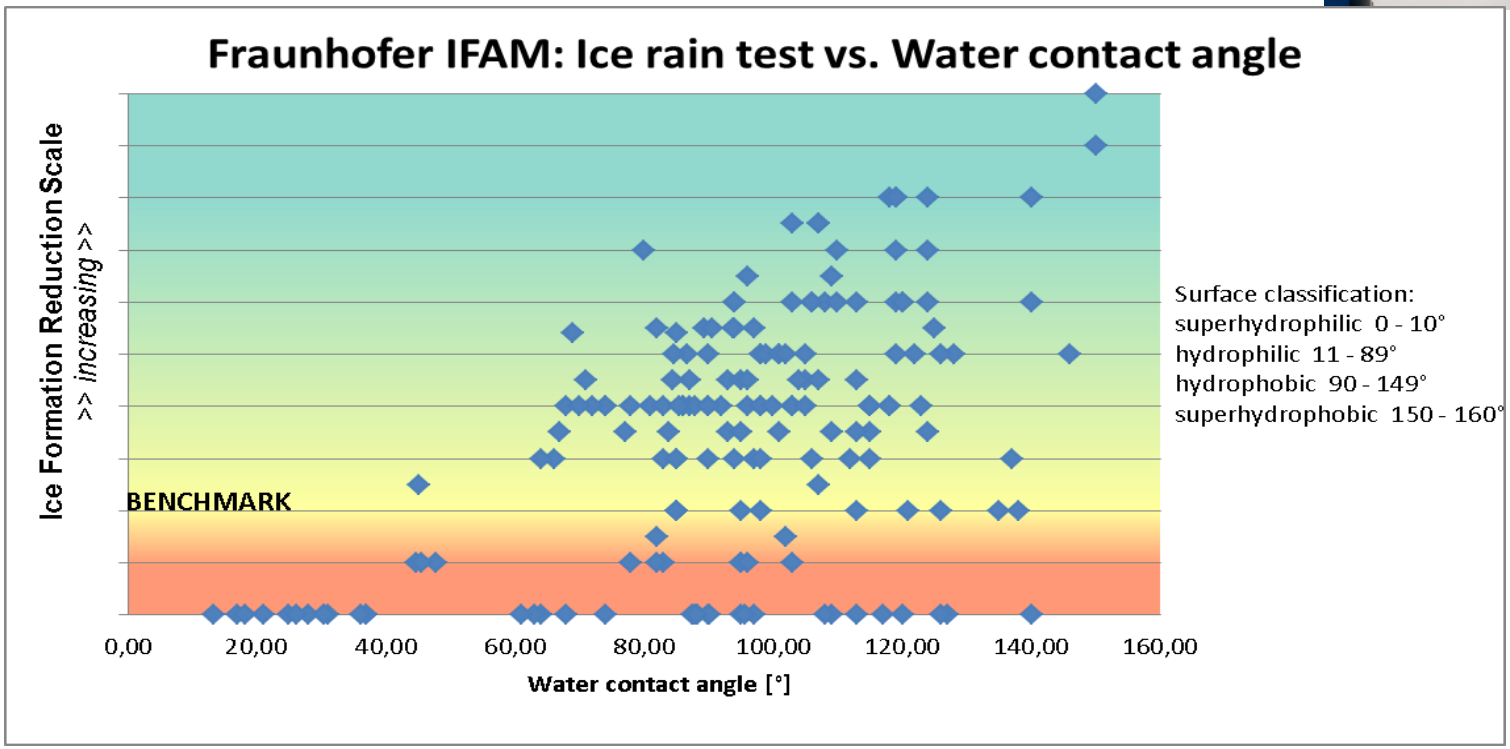
# Ice formation tests vs. Surface characteristics




→ Water contact angle (surface hydrophobicity) is NOT the key property for icephobic coatings

→ Parameters such as (1) Surface free energy, (2) contact angle hysteresis, (3) sliding angle are currently being discussed / evaluated in terms of correlations to icephobicity



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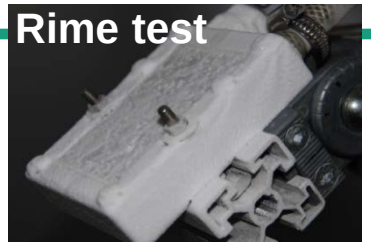
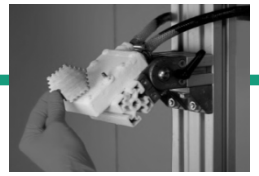
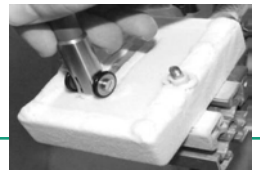
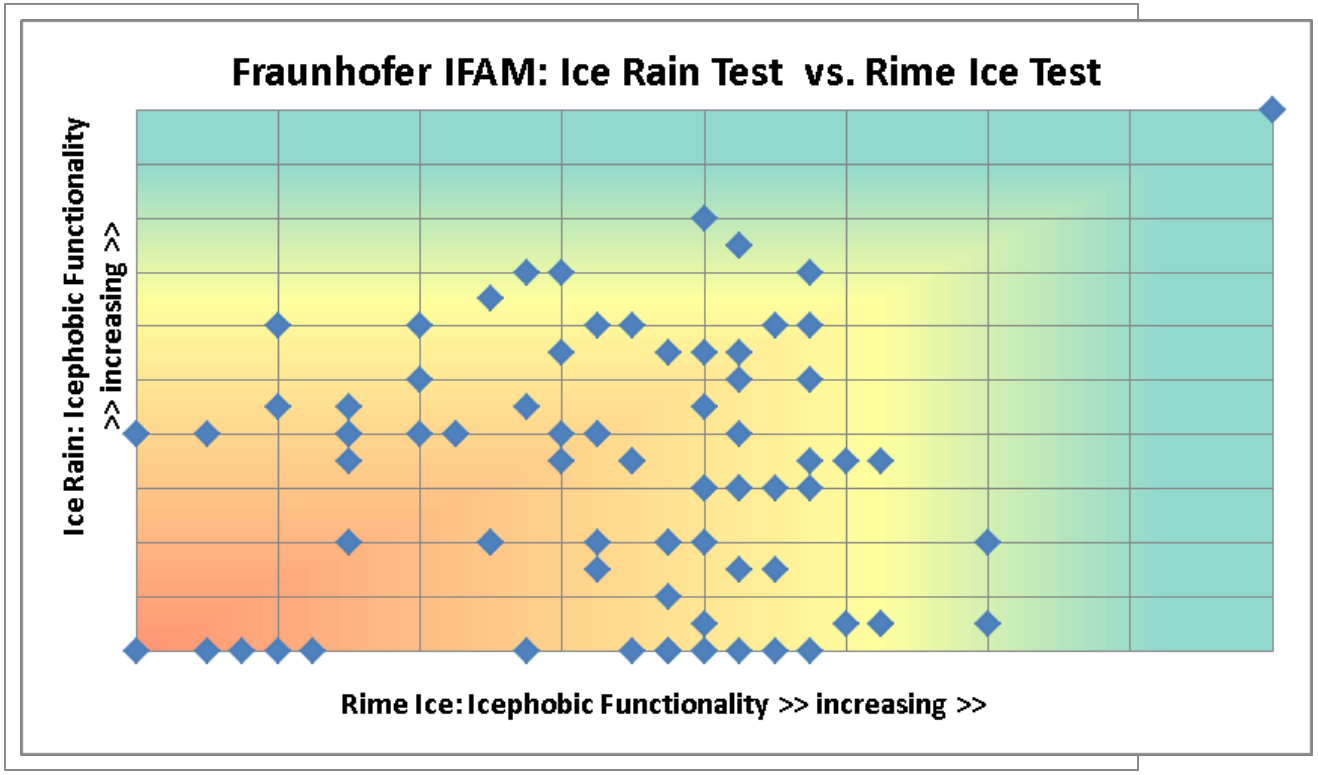
# Ice formation tests








→ Icephobicity of surfaces depends on ice type!



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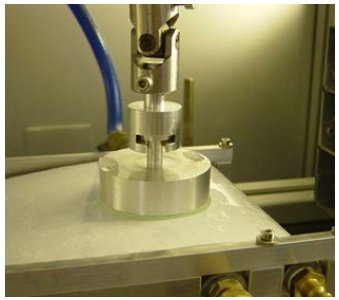
# Conclusions for Ice formation tests

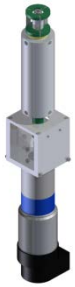
- INTERNALLY Standardized test methods allow comparison of materials regarding icephobic performance (Assessment against pre-defined benchmark)
- Results serve as basis for correlation assessment with surface parameters

- Risk: Harsher icing conditions  very quickly result in loss of icephobic properties!


- Further ice formation processes / ice adhesion or durability of coatings are not covered with these tests









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# Comparison of Ice-related tests

JEDI ACE
ICE PROTECTION TECHNOLOGIES FOR AIRCRAFT

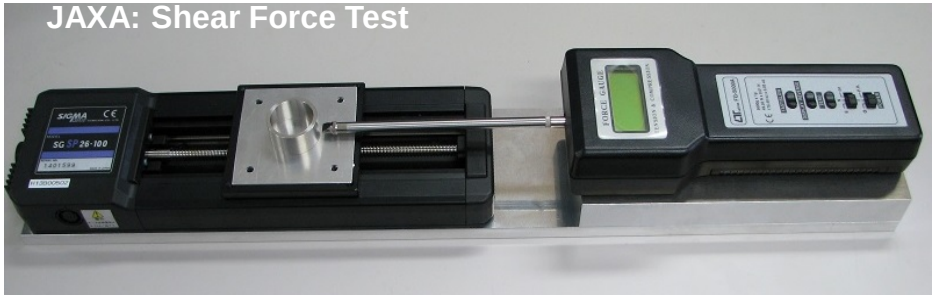
**Achievements resulting from European-Japanese cooperation:**

Evaluation of test methods for anti-icing coatings

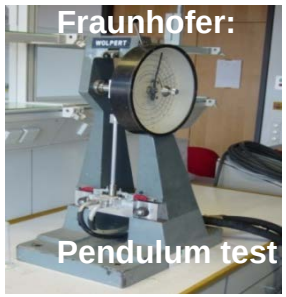
Assessment of surface properties and icing behavior prior to wind tunnel tests:











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# Comparison of Ice-related tests

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## Test results for anti-icing coatings:

| Coating class | Surface characteristics | | Ice formation | | Ice adhesion | |
|---|---|---|---|---|---|---|
| | Water contact angle [°] | Sliding angle [°] | **Ice Rain Test** (Fraunhofer IFAM) [% reduction] | **Spay Ice Test** (JAXA) [% reduction] | **Ring Pusher Test** (JAXA) [% reduction] | **Pendulum Test** (Fraunhofer IFAM) [% reduction] |
| PUR (benchmark) | 90 | >90 | (benchmark) | (benchmark) | (benchmark) | (benchmark) |
| Elastomeric, F-modified PUR | 100 | >90 | 50 | 50 | **90** | 35 |
| Superhydrophobic PUR | ≥150 | <10 | **>90** | 50 | 50 | **>90** |



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# Ice wind tunnel tests

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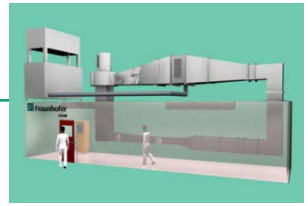


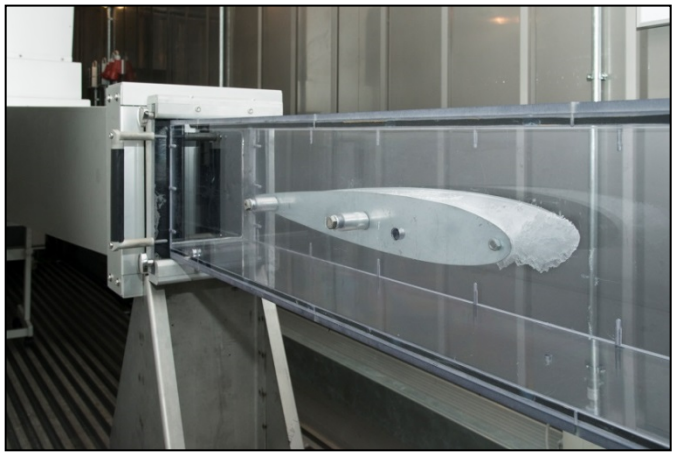
(1) Ice lab with temperatures down to -30°C, controlled humidity and additional test equipment

⇩

Allows research on icing processes and ice adhesion; Simulates conditions for cooling units, HVAC systems

(2) Wind tunnel with temp. down to -30°C, wind speed 350km/h, supercooled water droplets

Simulates conditions for e.g. aircraft, wind turbines





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# Ice wind tunnel test results

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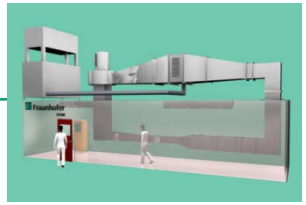
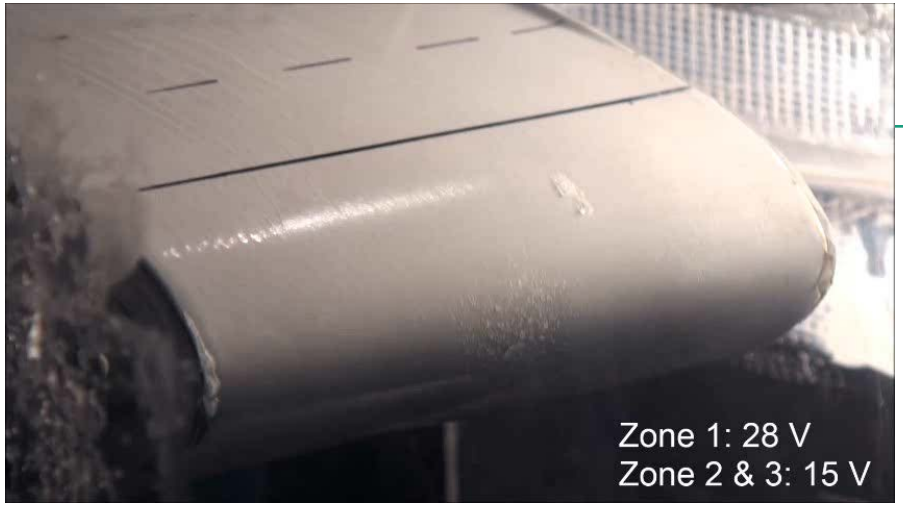
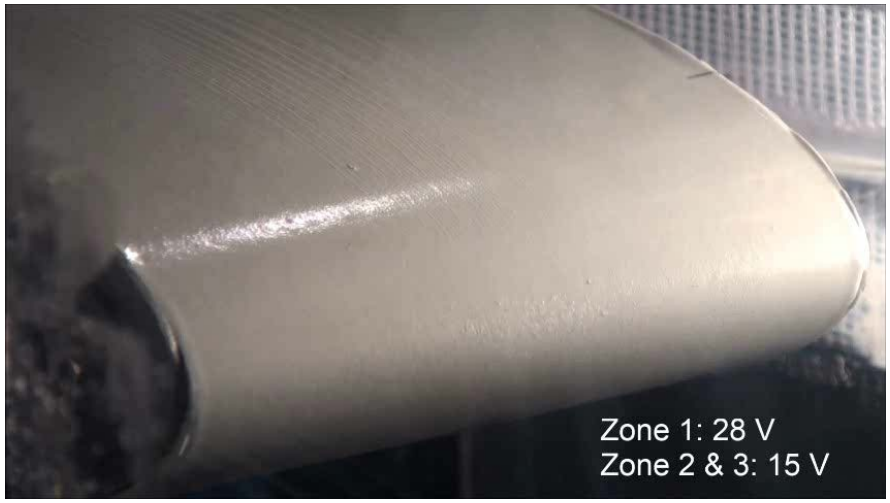


Formation of ice at leading edges – profiles equipped with heating devices and covered with different coatings

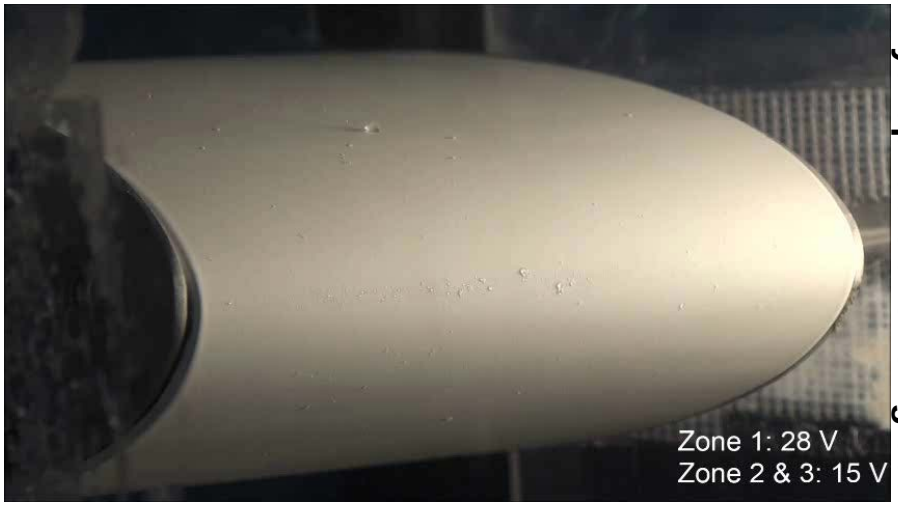
PUR benchmark coating




Elastomeric anti-icing coating




Superhydrophobic anti-icing coating



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# Ice wind tunnel test results

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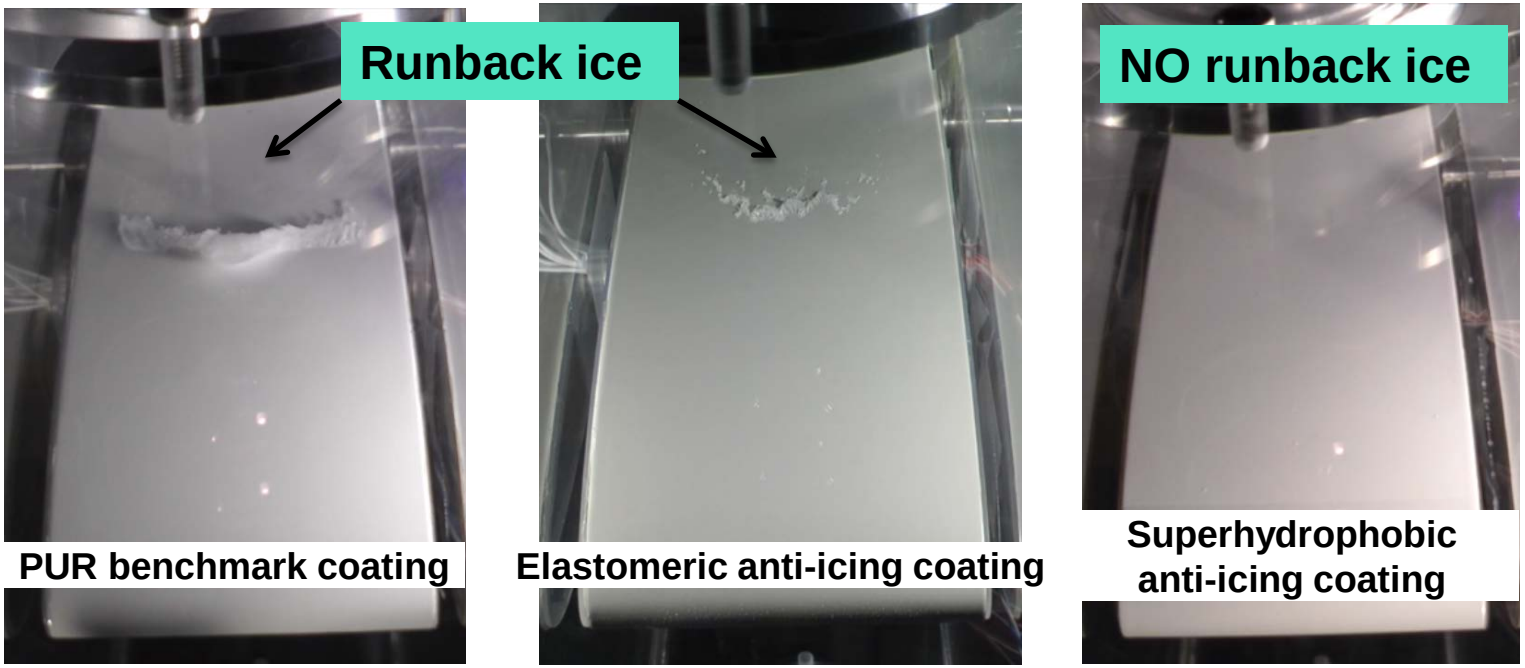
Kanagawa Institute of Technology, Japan
KAIT

Formation of runback ice on mock-ups, equipped with heating devices and covered with different coatings:




Developer of Icephobic surfaces needs to address ice formation process AND anti-icing / de-icing purposes!



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# Ice wind tunnel test results

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## Test results for anti-icing coatings:

| Coating class | **Impact icing** -leading edge- [power reduction] | **Runback icing** -unheated zone- [power reduction] |
|---|---|---|
| PUR (benchmark) | (benchmark) | (benchmark) |
| Elastomeric, F-modified PUR | **YES** | YES |
| Superhydrophobic PUR | NO | **BEST PERFORMING** |

- Developed coatings showed **icephobic properties** in all ice-related tests
- Combination of icephobic coatings with heating devices led to **significantly reduced energy consumption** in ice wind tunnel tests.
- Depending on **ice formation type** (Impact vs. Runback) different surface characteristics are required
- Trends in **lab-based tests and ice wind tunnel tests** could be observed



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# Conclusions / Outlook


Fraunhofer IFAM has gained a broad experience in testing icephobic materials.

Future needs would be:
Increase of available field data to further improve significance of lab-based tests / ice wind tunnel tests.

Optimize coating development with proven ice-related tests.

Cooperate with other research institutions and industry to use synergies for the complex tasks of icing research



Fraunhofer IFAM

International Workshop on
**Surface Icing and Assessment of De-Icing / Anti-Icing Technologies**
24 / 25 January 2017; Fraunhofer IFAM, Bremen, Germany

Aim: bringing together experts from research institutions and industry sectors to discuss most prominent needs in the field of surface icing

55 Participants from:

15 research institutions
24 companies

Mainly from:
Aircraft sector
Wind energy
Coating manufacturers and
Heating / sensor technologies




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# Conclusions of the Workshop Outlook

--> Promising heating as well as surface technologies are under development. **Lack of industry requirements** especially in the field of surfaces is of concern and may result in uncertainties in actual material performance.

--> **Standardization of test methods** (especially ice adhesion) is required as one important step towards requirement definition. Previous activities will be used to define the next steps.

--> There is limited experience in terms of ice-related lab tests, ice wind tunnel tests, and field tests available. However, the **significance of lab tests** needs to be proven to further improve development processes. Activities are ongoing, and the industry sector is asked to support research institutions in that field.

--> Despite the long history of icing research, **no general conclusions about beneficial anti-ice surface characteristics** can be drawn. This is strongly influenced by the process of ice formation. Simulations taking into account surface parameters may help in the future. In summary: this results in a need for further fundamental research.

--> **Durability** of surfaces is of major concern.

--> There are similarities - but also significant differences in aircraft / wind energy sectors.

# Many thanks for your attention!

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