Assessment of De-icing and Anti-icing technologies in ice wind tunnel

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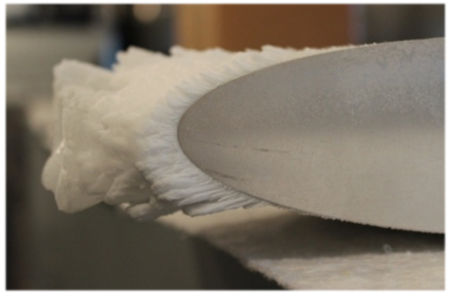
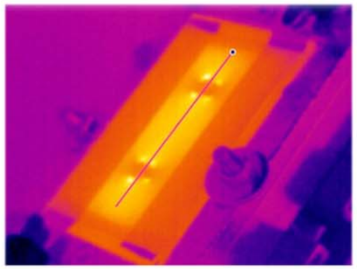
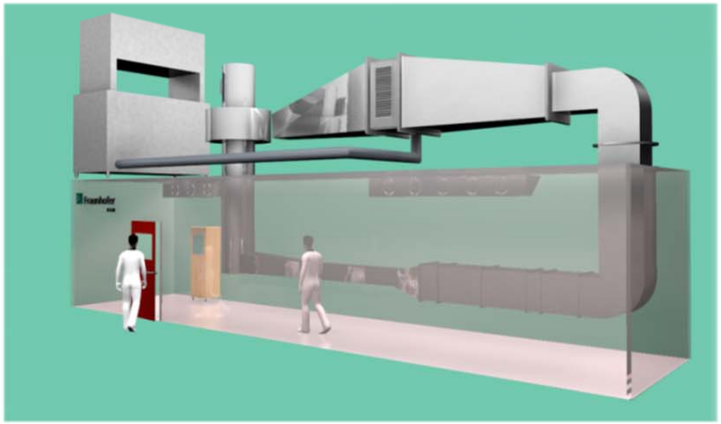


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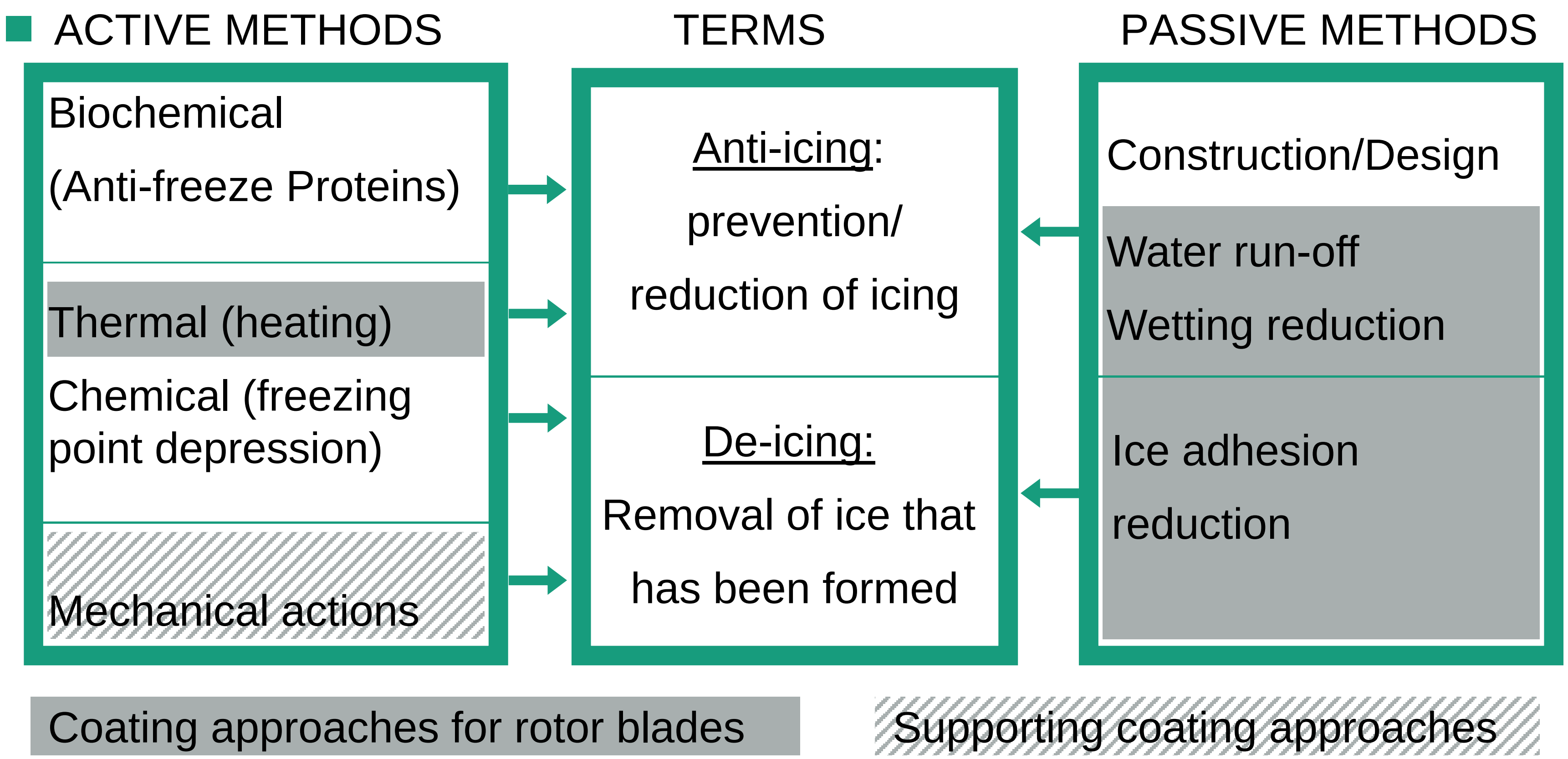
Content

- Introduction: anti-icing / de-icing technologies
- HEATING for anti-icing / de-icing purposes
    - Electro-thermal heatable coatings
    - Inductive heating
- ICEPHOBIC COATINGS
    - Approaches and challenges
- ICE WIND TUNNEL TESTS
- Conclusions

Terms / methods related to icing:



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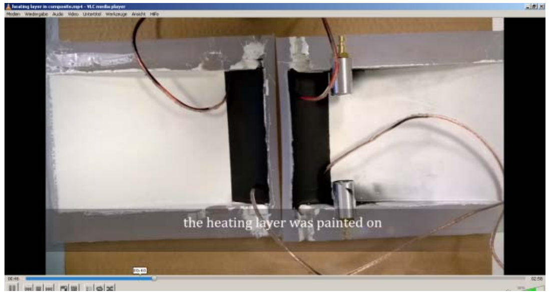
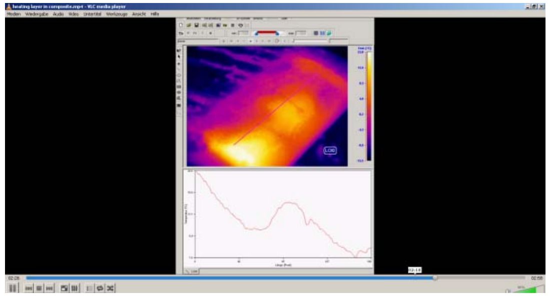
HEATING:
Electro-thermal approach

- Technical solutions for rotor blades:
  - Heating of the inner part of the blade by using hot air
  - Use of heating mats / heating foils close to surface
  - Microwave technology, Induction heating

  - HEATABLE COATINGS with following properties
    - Applicable in-mold, spray, retro-fit
    - Application also on curved / complex geometries
    - Repairable
    - Embedding in coating system with close situation to ice-surface interface





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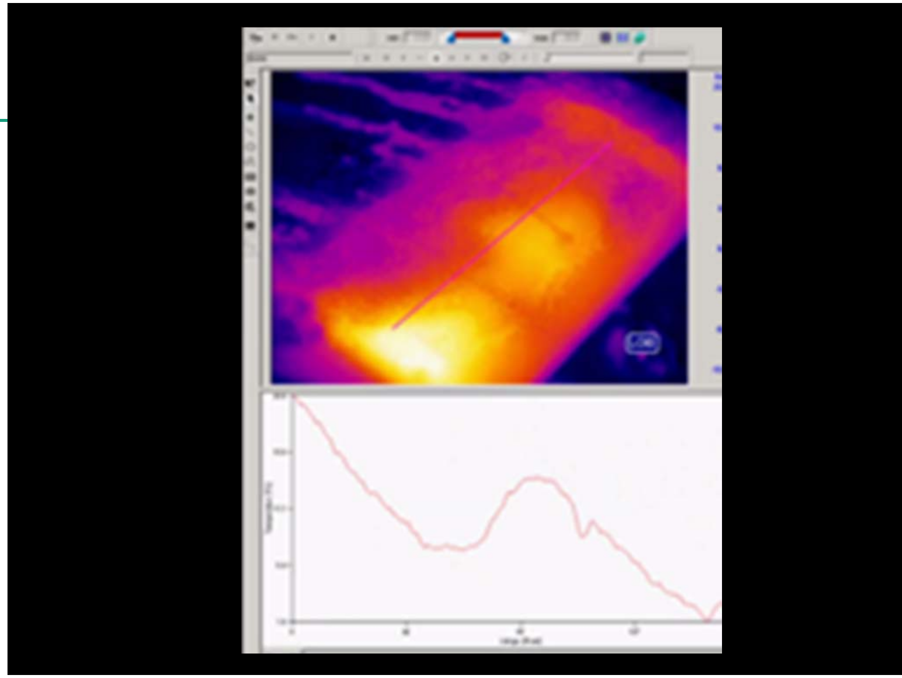
Heatable coatings

- Electrically conductive layers
  as resistance heater:



- Parameters for layer effectivity:
  - Conductivity of pigments (building an electrically conductive network within the coating)
  - Pigment / Binder ratio (percolation threshhold)
  - Pigment shape (aspect ratio) and orientation in coating matrix

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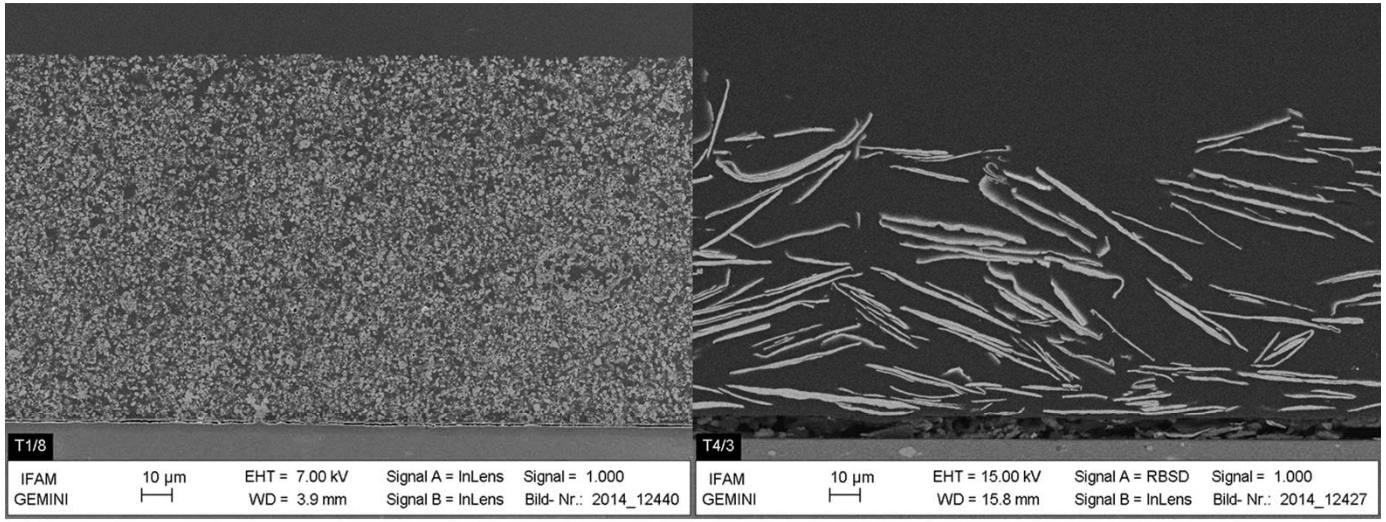
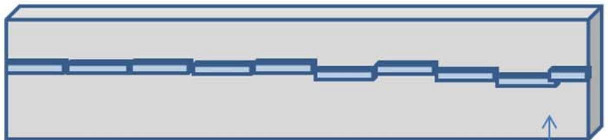
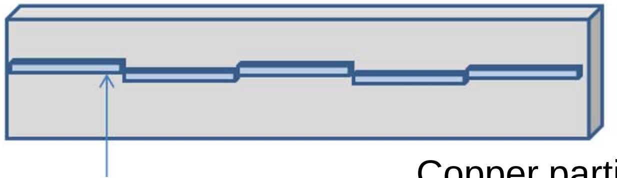
Heatable coatings







Silver particles 80%
spherical 0,6µm-2,3µm

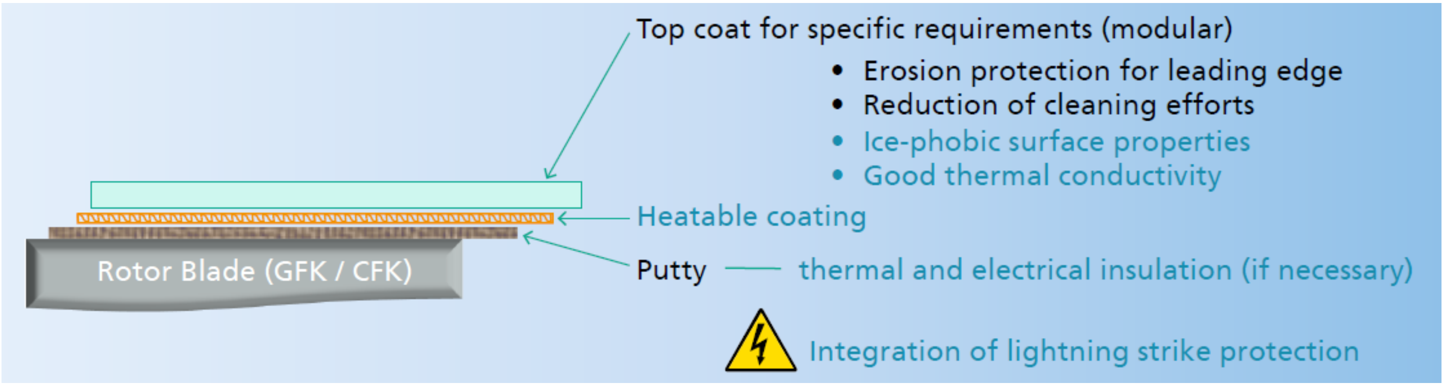
Coating matrix

Electrically conductive particles

Copper particles 34%
flaky 16µm-72µm

Heatable coatings - concept

- Concept for integration of heating layer to fulfil technical requirements:

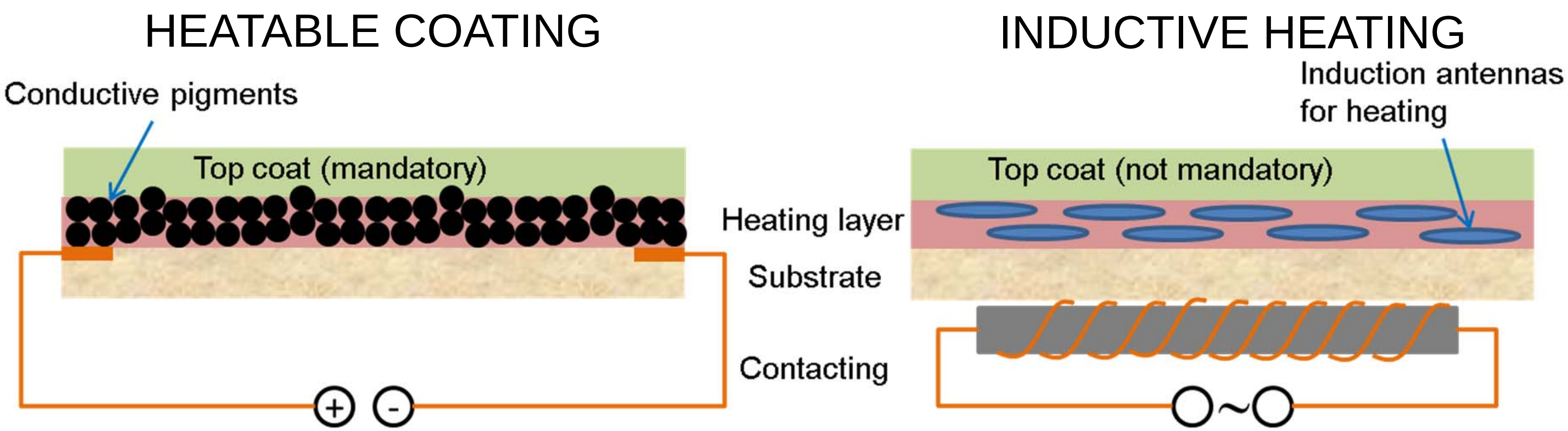


- Material and concept development ongoing at Fraunhofer IFAM, linked to comprehensive testing in ice wind tunnel

- Integration of ice protection system with ice sensors and control systems necessary for improved energy efficiency / Integration of ice protection system in wind turbine – open tasks for development partners

Inductive heating - concept

- Heating concept using electromagnetic induction



- Main advantages:
  - Electrical connection in coating layers not necessary
  - Lightning strike problems significantly reduced
- Main challenge:
  - Development status clearly lower compared to heatable coatings

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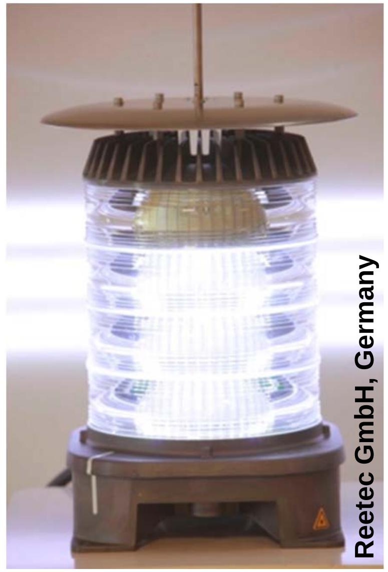
Icephobic coatings
How can a coating act?

Influencing parameters for ice formation:

✓ Surface temperature
- Surface chemistry
- Surface topography
- Surface physics

Mode of action for icephobic coatings:

- Minimization of wetting
- Acceleration of water run-off
- Reduction of ice adhesion



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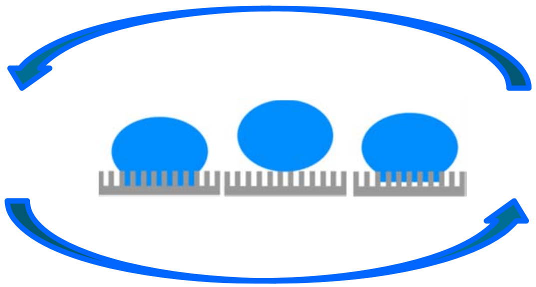
Icephobic coatings

Combination of electro-thermal method with icephobic surfaces

→ significant reduction in energy consumption proven (in lab-scale)

Influencing parameters for ice formation:

Chemical-based:
minimization of bonding options between water molecules and coating surface; Preferably NO electrostatic interactions, hydrogen bonding, and van-der-Waals interactions



Physical-based:
micro- and nanoscale surface topography with significant effects on wetting and ice adhesion; preferably Cassie-Baxter (droplet with minimum contact to surface)

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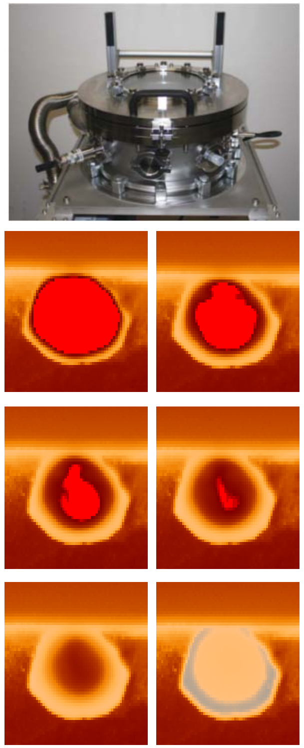
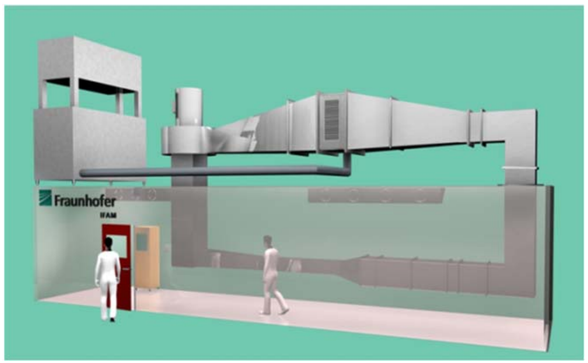
Assessment of icing processes and anti-icing / de-icing technologies

- from microscopic view, lab simulation tests to field tests





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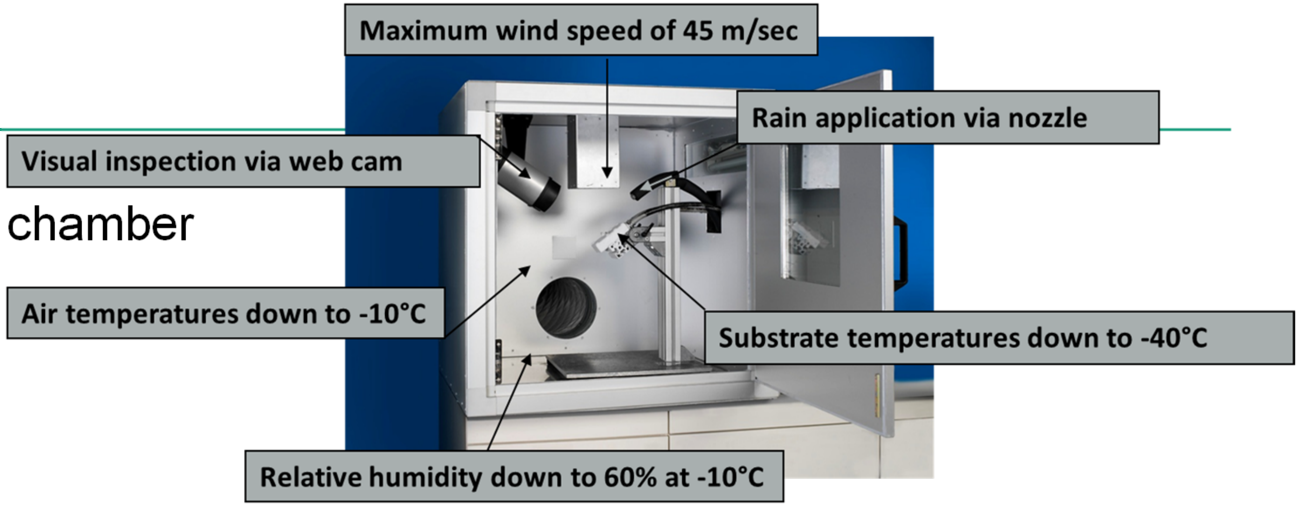
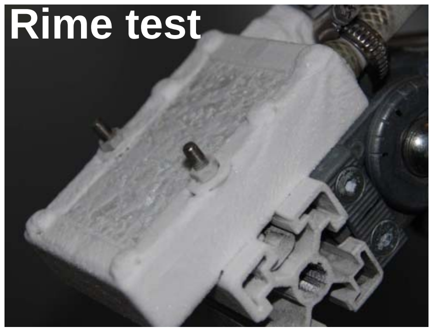
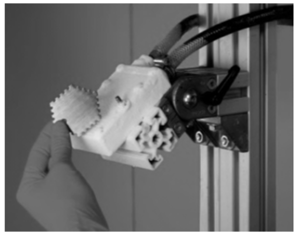
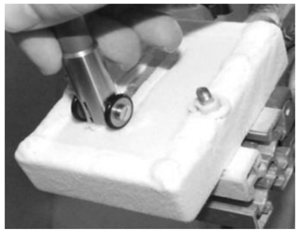
Ice-related tests

- Standard IFAM icing chamber

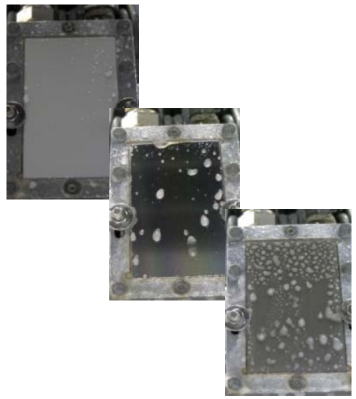








Simulates formation and adhesion of rime



Simulates water run-off and subsequent formation of clear ice

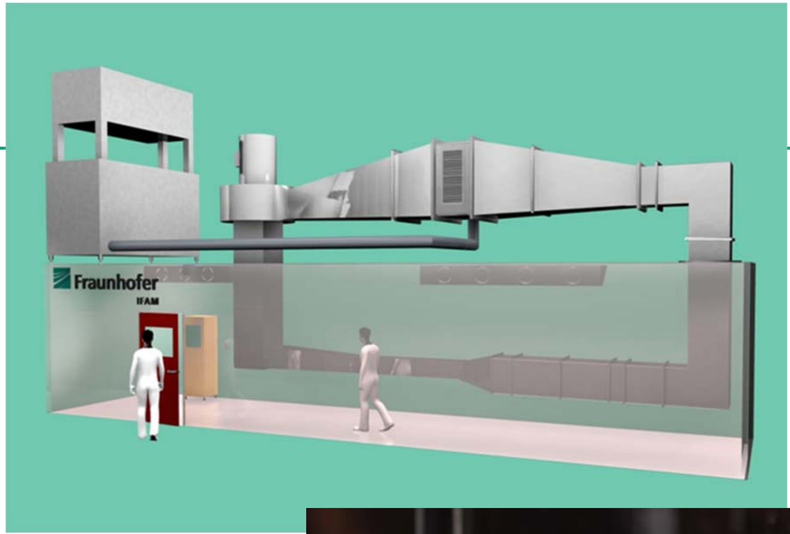
Icephobic coatings

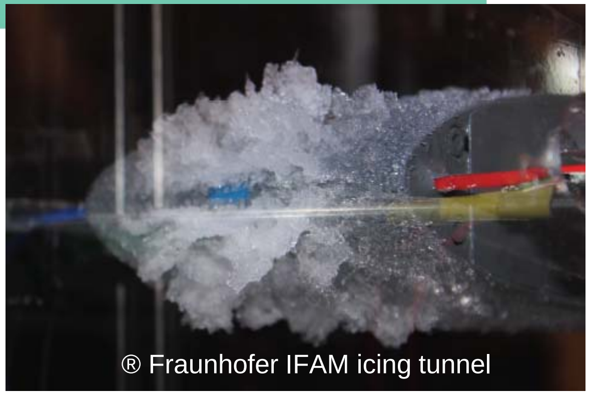
- One Example:

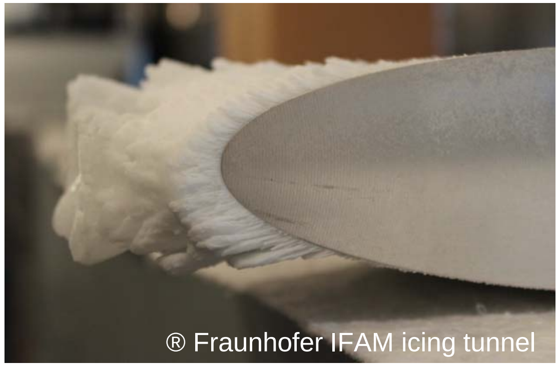
Parameter	**Unmodified PUR**	**F-modified PUR coating**
Water contact angle [°] Roughness Ra [µm]	82 0.17 (±0.01)	124 0.64 (±0.07)
Ice formation at -5°C in IFAM ice rain test		
Ice adhesion	Significant ice adhesion reduction	
Limitation	Rime ice accretion is not prevented	

Ice-related tests

- ICE/lab with integrated ice wind tunnel for simulation of icing conditions relevant for many technical applications:
  - temperature down to -30°C
  - wind speed of up to 350km/h,
  - water droplets (incl. supercooled)




® Fraunhofer IFAM icing tunnel


® Fraunhofer IFAM icing tunnel

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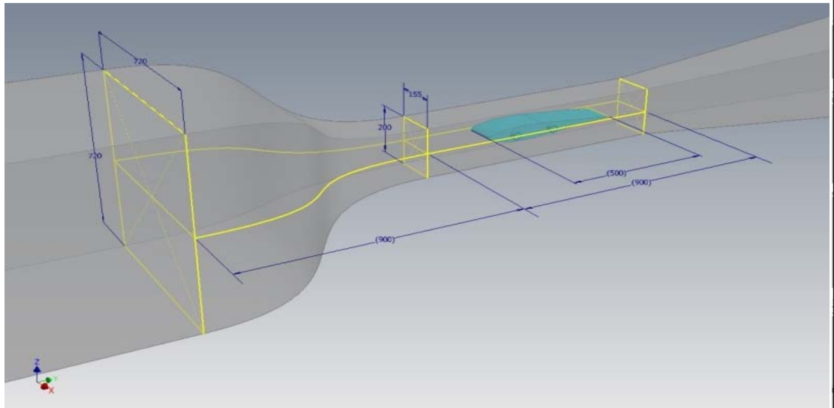
Ice wind tunnel tests



SAE ARP5905

5. FACILITY PERFORMANCE TARGETS:

Icing testing should be performed in facilities having measured, defined, and documented aero-thermodynamic flow qualities, icing cloud qualities, and calibrated instrumentation. The facility should be calibrated in accordance with the time frames in Section 7 and the procedures in Section 8. The test section airflow and icing cloud characteristics should be within the range of performance targets listed in Table 1 over the area of the uniform icing cloud. The uniform icing cloud is defined as the area of the test section over which the LWC does not vary by more than ±20% from the test section centerline LWC value for a given airspeed and water droplet size.

TABLE 1 - Test Section Performance Targets[1]

	Measurement Instrumentation Maximum Uncertainty[2]	Tunnel Centerline Temporal Stability[3]	Spatial Uniformity[4]	Limit Value[5]
Aerodynamic Parameters				
Airspeed	±1%	±2%	±2%	N/A
Static Air Temperature below -30 °C	±2 °C	±2 °C	±2 °C	N/A
Static Air Temperature between -30 and +5 °C	±0.5 °C	±0.5 °C	±1 °C	N/A
Flow Angularity	±0.25°	N/A	±2°	±3°
Flow Turbulence				
(P_a-Off)[6]	±0.25%	±2%	<2%	2%[8]
(P_a-On)[7]	±0.25%	±2%	<2%	5%[8]
Pressure Altitude	±50 m	±50 m	N/A	N/A
Cloud Uniformity Parameters				
Liquid Water Content	±10%	±20%	±20%	N/A
Median Volume Diameter[9]	±10%	±10%	N/A	N/A
Relative Humidity	±3%	N/A	N/A	N/A

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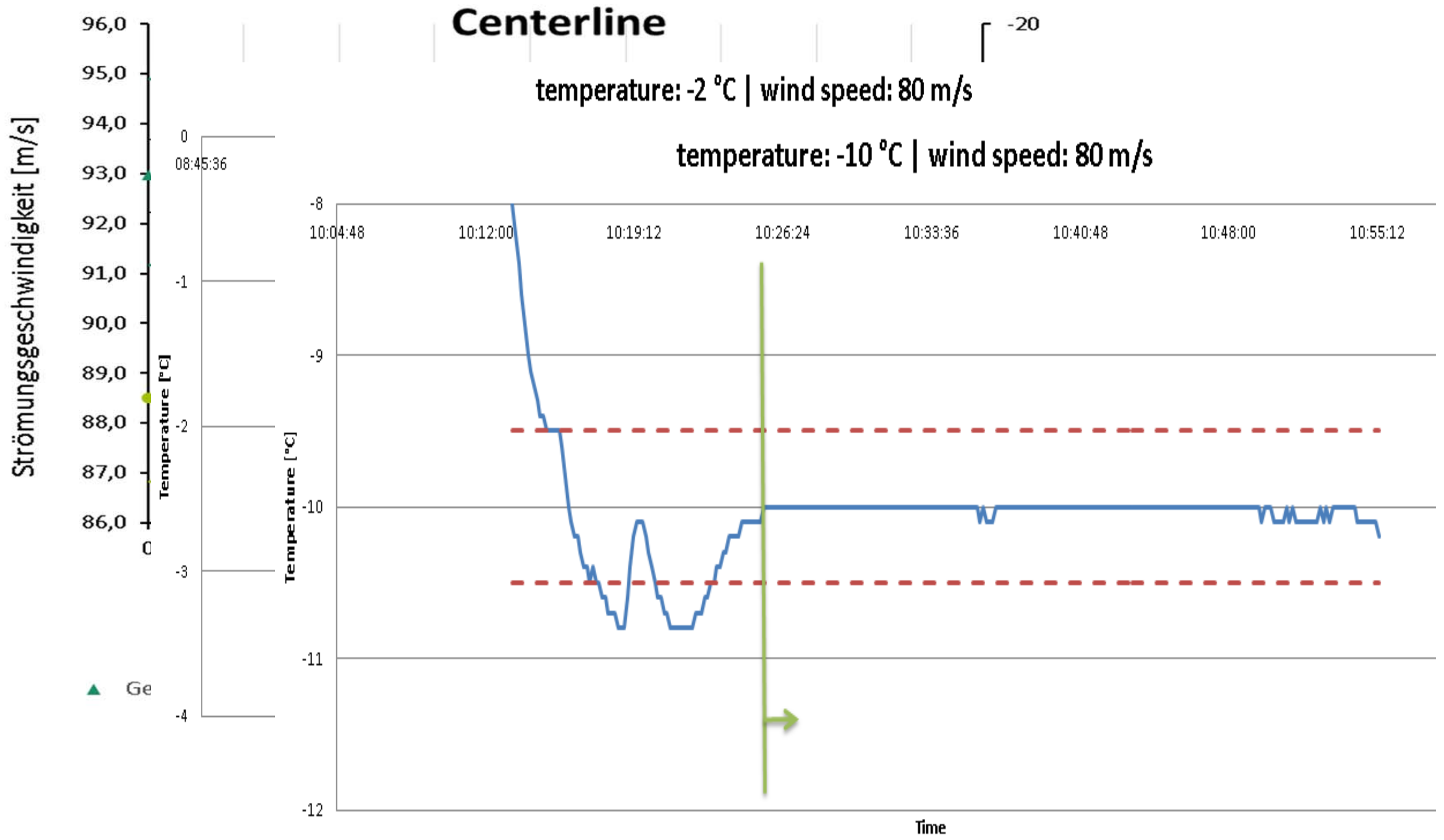
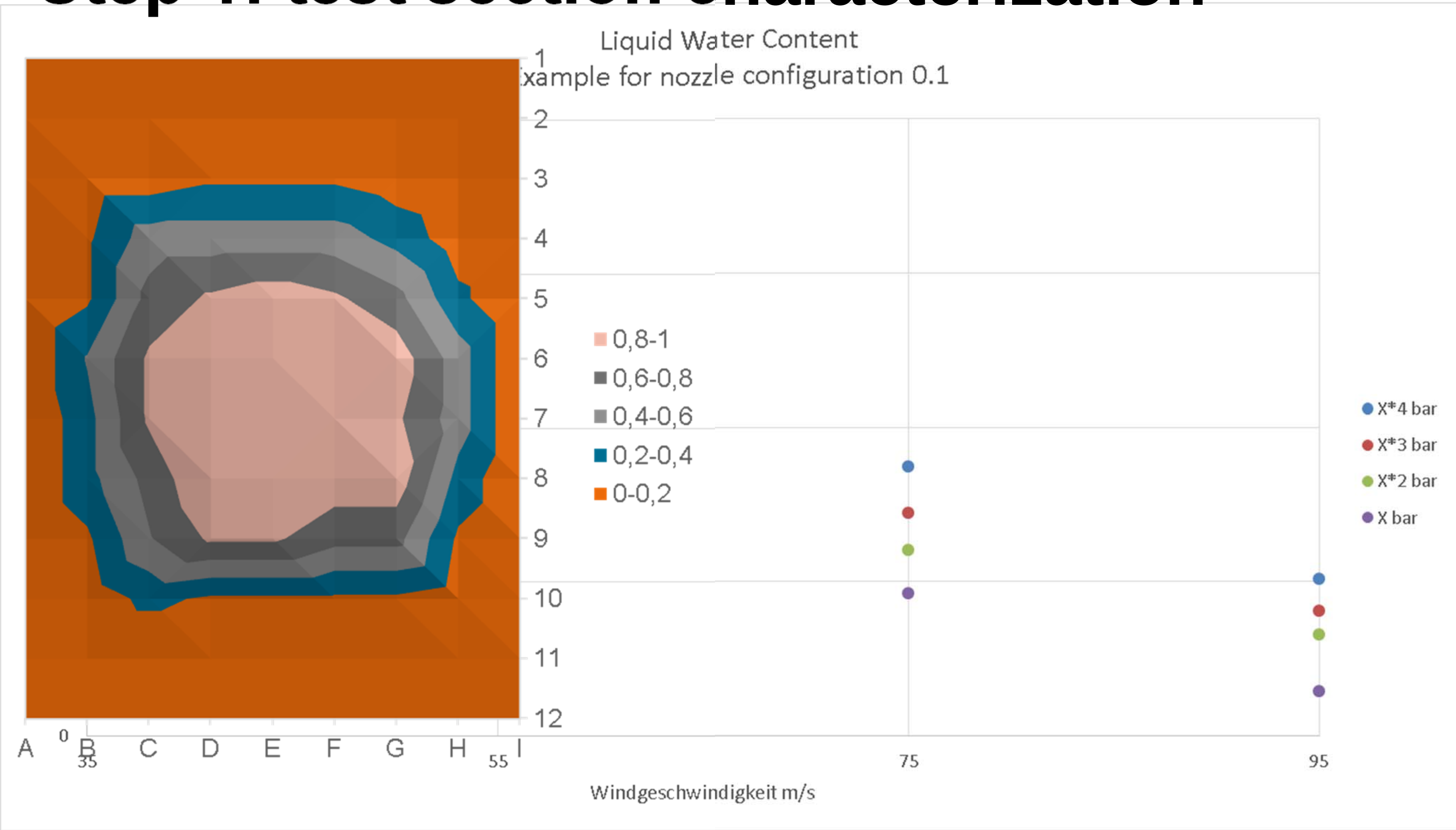
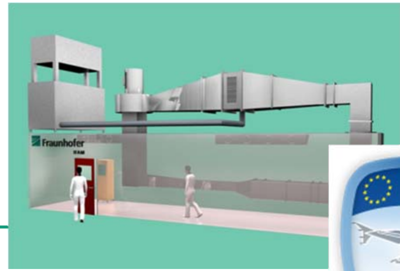
Ice wind tunnel tests
Step 1: test section characterization

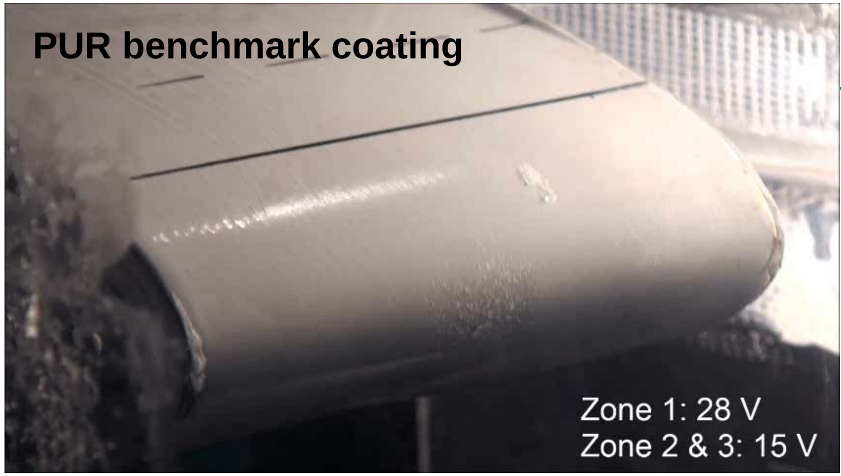


Ice wind tunnel tests
Step 1: test section characterization

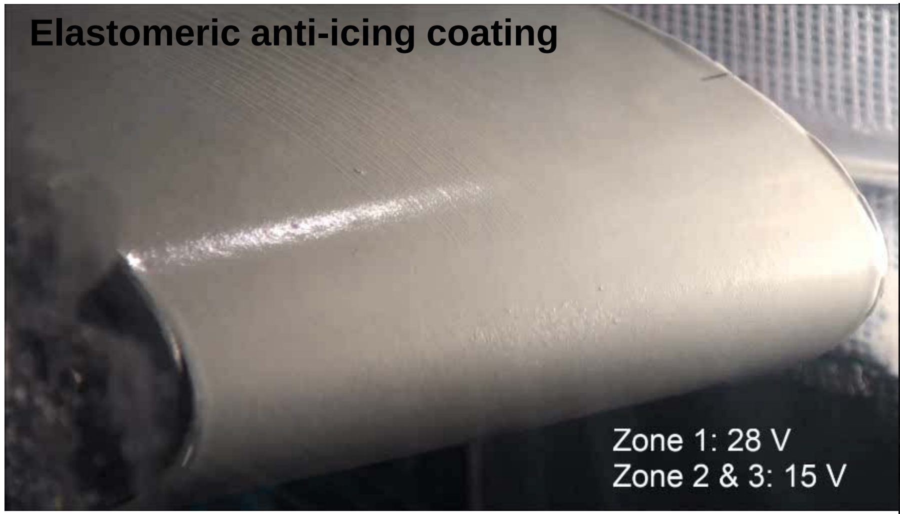


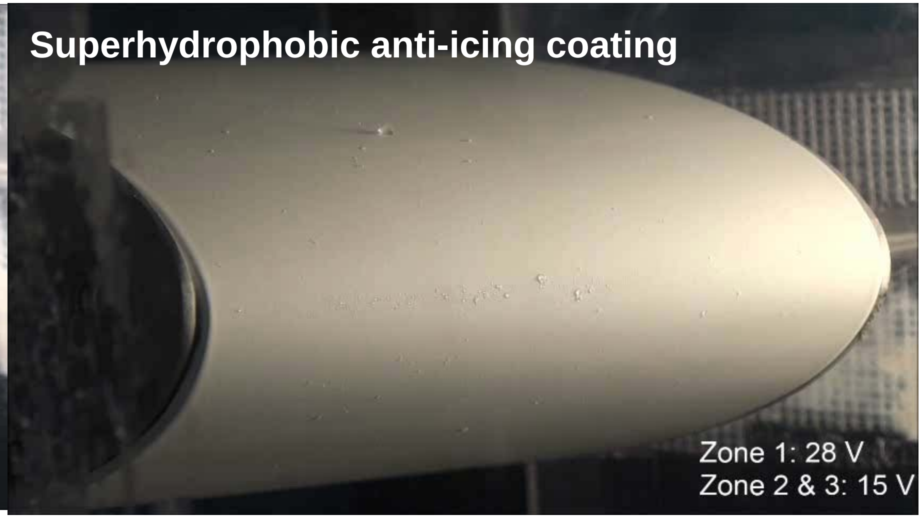
Ice wind tunnel test results





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





Ice wind tunnel test results

Kanagawa Institute of Technology, Japan

KAIT

JEDI ACE

ICE PROTECTION TECHNOLOGIES FOR AIRCRAFT

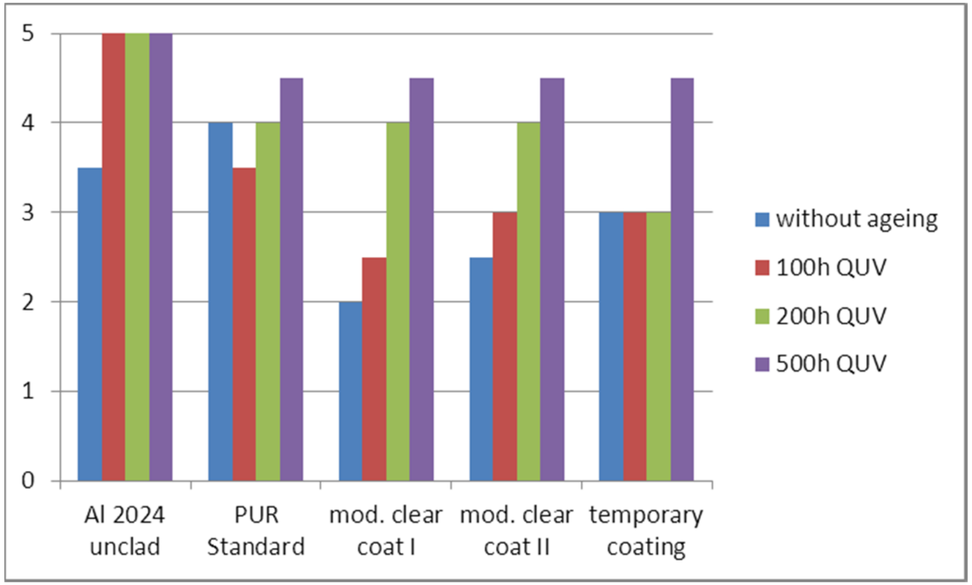
Formation of runback ice on mock-ups, equipped with heating devices and covered with different coatings:

PUR benchmark coating | **Elastomeric anti-icing coating** | **Superhydrophobic anti-icing coating**

Icephobic coatings
Challenges

- Selection of icephobic coatings depending on icing process
- Many hydrophobic coatings available on the market – Limitations:
  - **Hydrophobicity is not necessarily associated with anti-icing properties!**

- Current challenges:
  - Multi-functional properties of top coat
  - Selection of additives that are not banned due to HSE-reasons
  - Improvement of long-term performance →



Results of “Ice rain test”: 0 – no ice to 5 – severe ice

Conclusions

- Different promising technologies for cold climate wind turbines are available / under development
- There are still various opportunities to further improve available technologies
- Heatable coatings are one option for advanced systems
- Icephobic surfaces are an interesting option to significantly reduce energy consumption
- Coating selection needs to address icing scenarios as efficiency of icephobic or superhydrophobic coatings differs significantly depending on icing process
- Interdisciplinary concepts need to be developed for integration in wind turbine technique / systems

Many thanks for your attention!

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