ANTI-ICING COATINGS AND DE-ICING

TECHNICAL APPROACHES AND STATUS

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- Introduction: General anti-ice aspects
- Evaluation of anti-ice coatings at Fraunhofer IFAM
  - Ice formation tests
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- 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

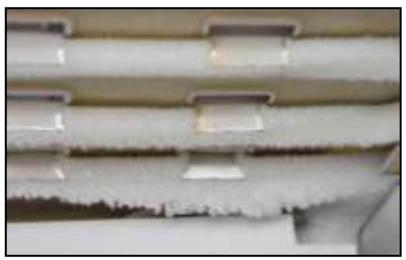
Anti-ice and de-icing coating concepts are relevant for varying technical fields:

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)

lead to

Tailor-made coatings for respective technical application

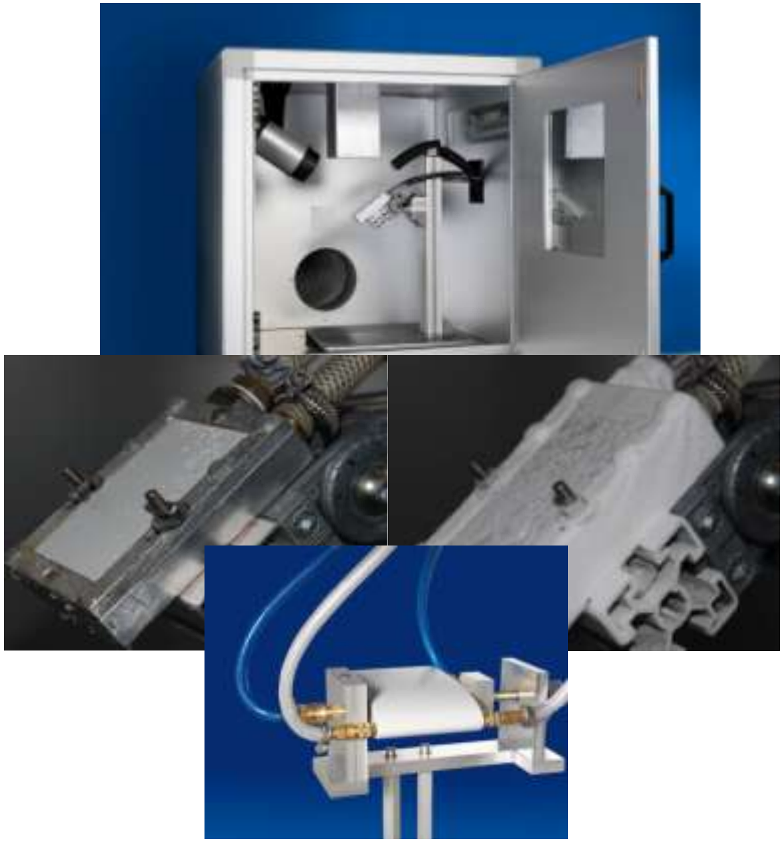
To achieve this you will need:

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

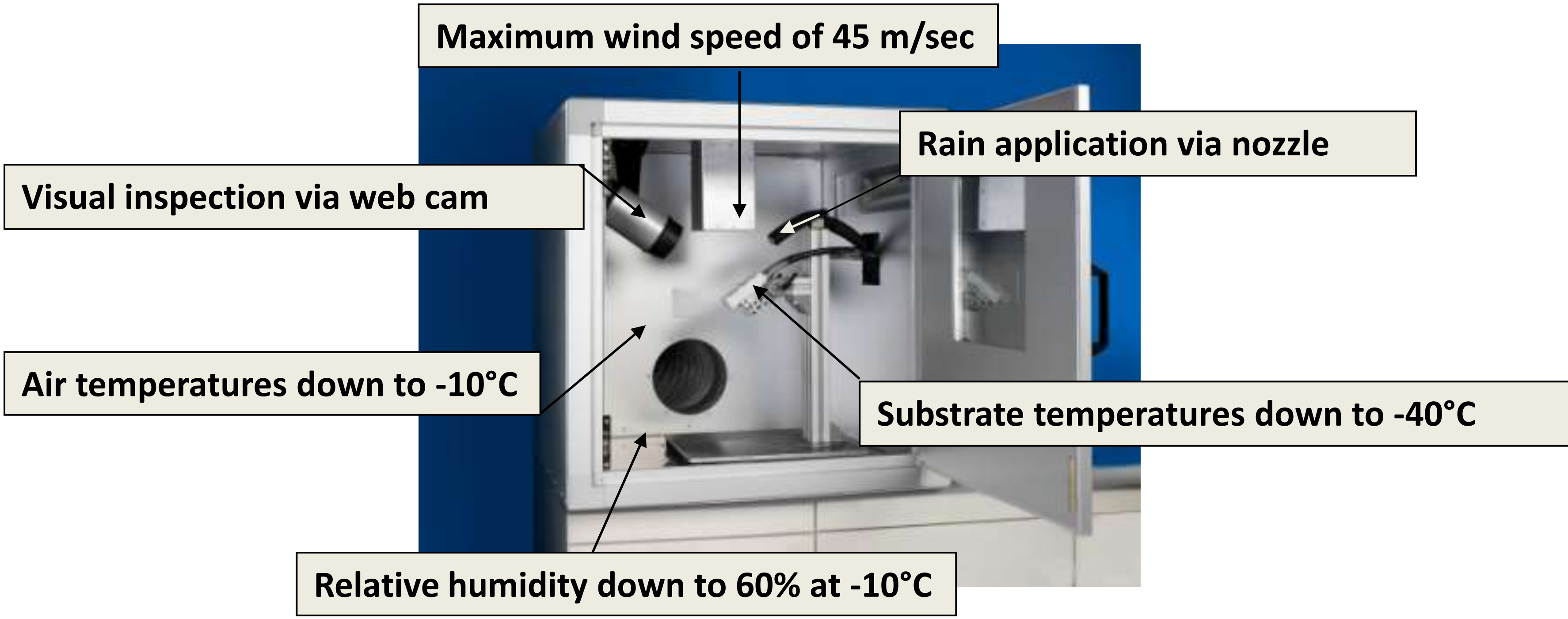


ice rain, rime and runback-ice tests

Ice adhesion tests

tests under real contitions

IFAM ice chamber for evaluation of anti-ice coatings:



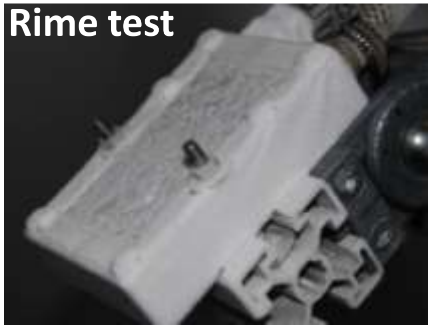
Conventional approach for anti-icing: Hydrophobicity

IFAM ice chamber tests: standard test scenarios

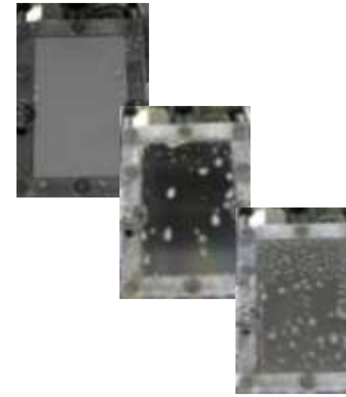
Ice rain test:
Simulates run-off behaviour of water and subsequent formation of clear ice

Rime test:
Simulates the formation of rime

Ice formation tests



Simulates formation of rime



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

<u>Test conditions</u>

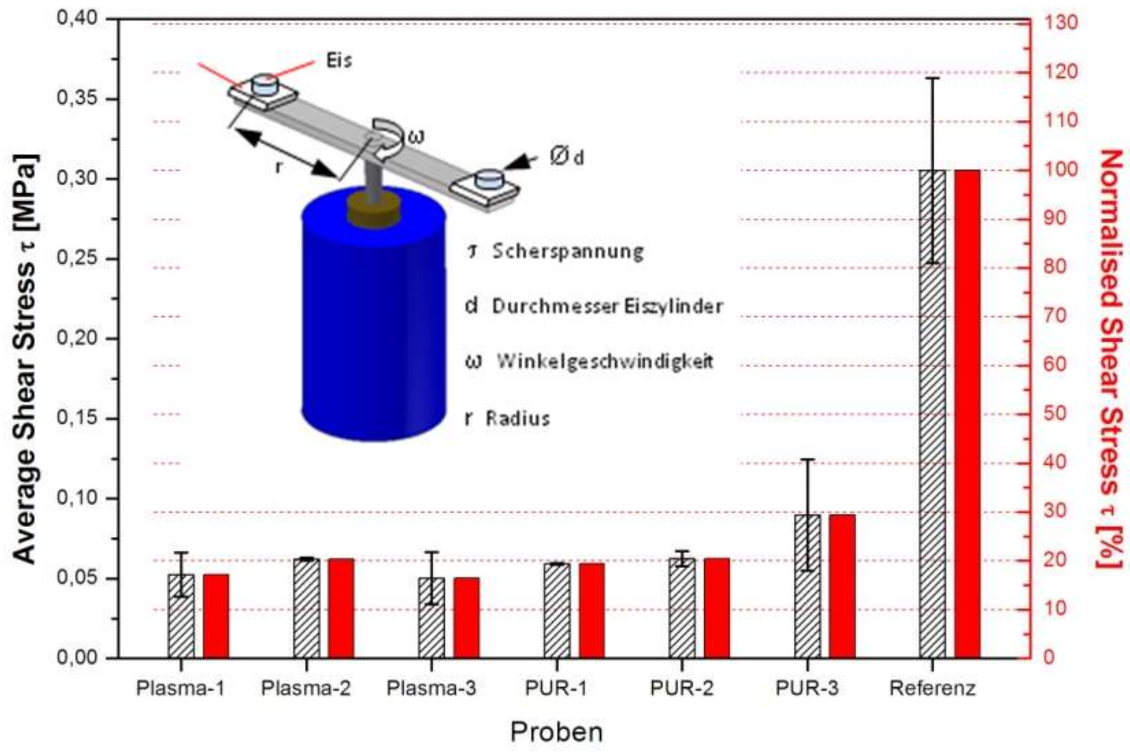
Rime test		Ice rain test
+1°C	**Air temperature**	-5°C
-2°C	**Substrate temperature**	down to -5°C
88%	**Relative humidity**	66%
9 m/sec	**Wind speed**	9 m/sec
/	**Rain duration**	10 seconds
rime thickness and adhesion	**Assessment**	visual inspection 10 min after raining

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)

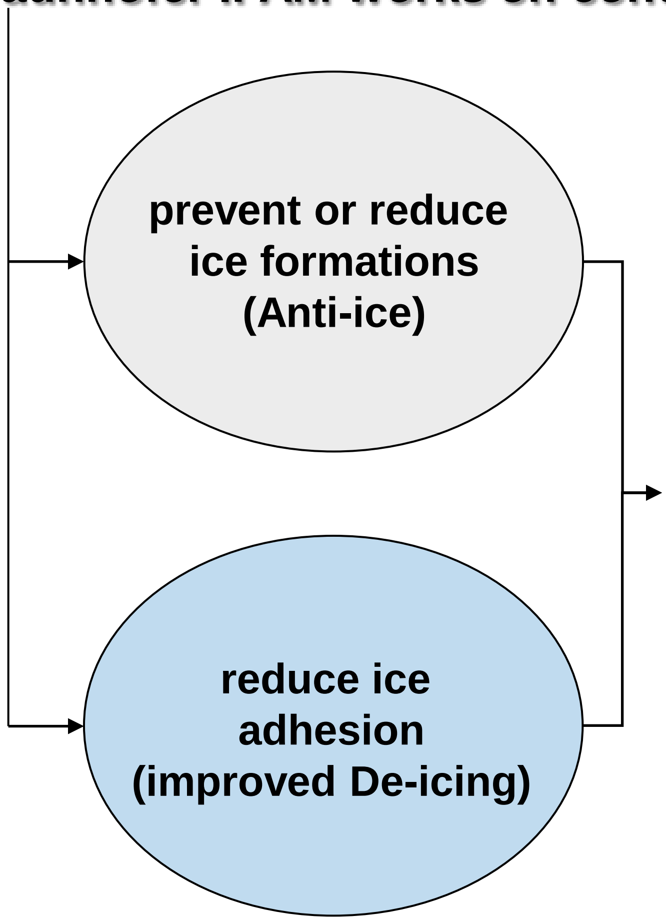
Long-term ice tests on the Mt. Brocken (height: 1141,1m)

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



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%

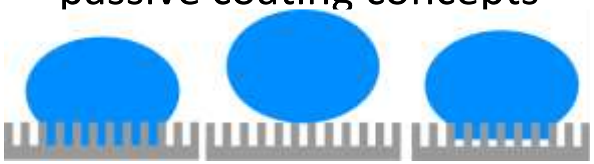
Development and Evaluation of anti-ice functional surfaces and coating concepts

Generell technological approaches for Anti-ice coatings work at IFAM

micro/nano-structured coatings
(via particel) inorganic organic

Sol-Gel coatings
(hydrophobe)

passive coating concepts



hydrophile / hydrophobe
coatings

interfacial structuring
(UV-process, photolithography)

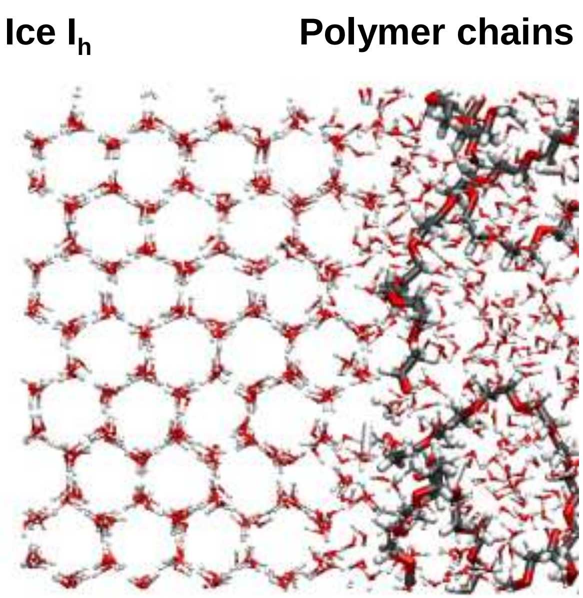
Performance Availability Applicability Requirements

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.”

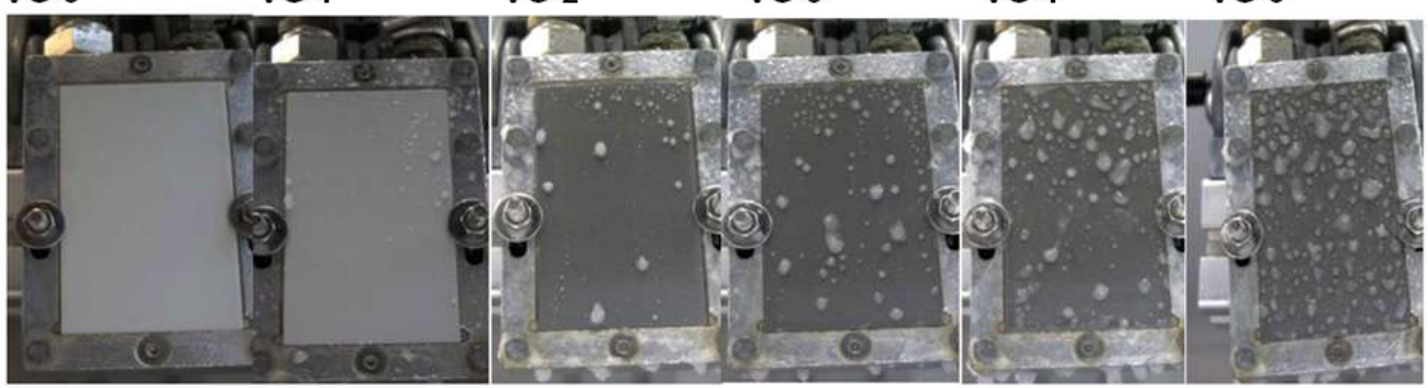


In this project, a polymer route was investigated Coblock polymers (PEG, - NHR) in the polymer matrix and one
-> Paint formulation route (2 K PUR, Sol-gel, UV curable coatings) and their influence on the anti-ice determines properties.

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

Ice grade Table

Ice grade/ Description	0 / Ice-free (Pictures show sample surfaces before sprinkling)	1 / Nearly ice-free Only a few, relatively small water droplets on the surface.	2 / Isolated ice Droplets Small to medium sized droplets – most part of surface is ice-free.	3 / Moderate ice formation Ice droplets relatively evenly distributed, but also ice free areas present.	4 / Enhanced ice Formation Most part of surface is covered by ice.	5/ Extensive and (nearly) complete ice coverage, respectively.
Photo 10 min after rain ice formation	VG-0	VG-1	VG-2	VG-3	VG-4	VG-5



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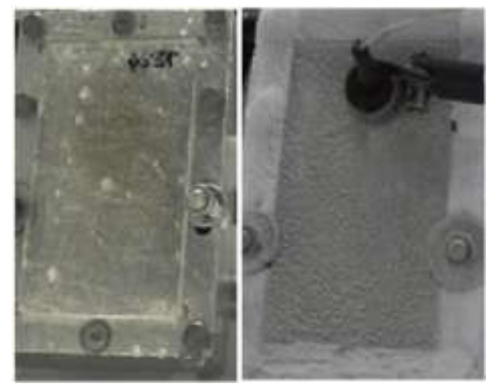
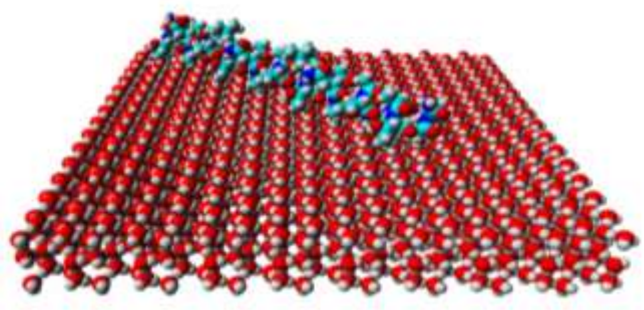
Investigations on the influence of key parameters on the icing behaviour

of transparent nano composite coatings for plastic surfaces (PMMA): Optimal balance of hydrophobicity, low surface energy and transparent scrach resistent surface were achieved with Perfluorpolyether (PFPE) and amorphous Silicate-nano (SiO_2) particel modified coatings

Parameter	**Unmodified PMMA**	**Passive transparent anti-ice coating**
Water contact angle [°]	80	115
Surface energy σ [mN/m]	**42.0** (σ_d =38.0; σ_p =3.4)	**11.2** (σ_d =10.6; σ_p =0.4)
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
Description of results 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**

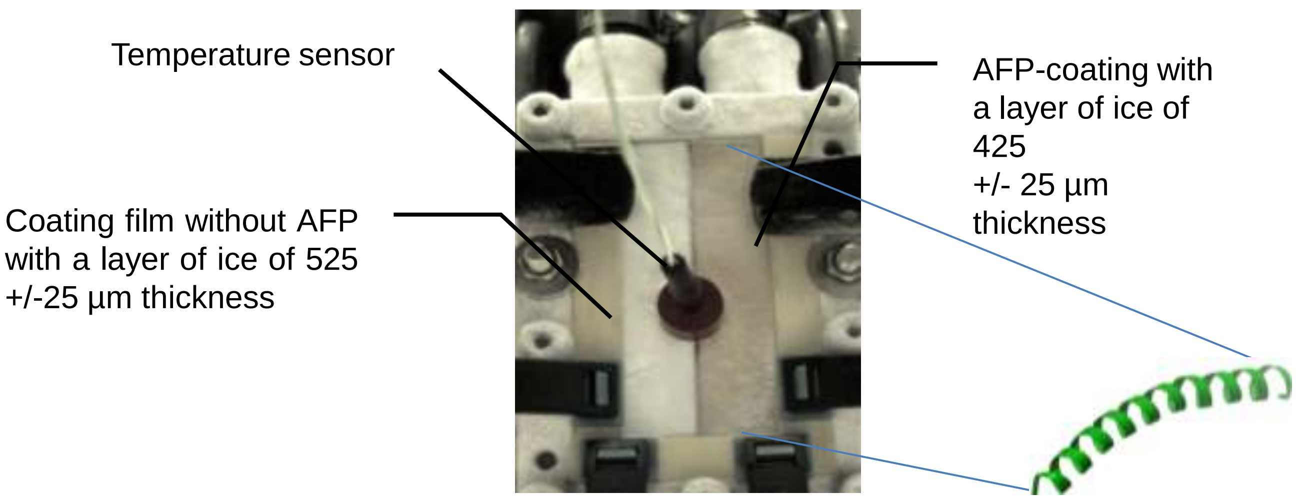
Biochemical (biomimetic) approach



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:



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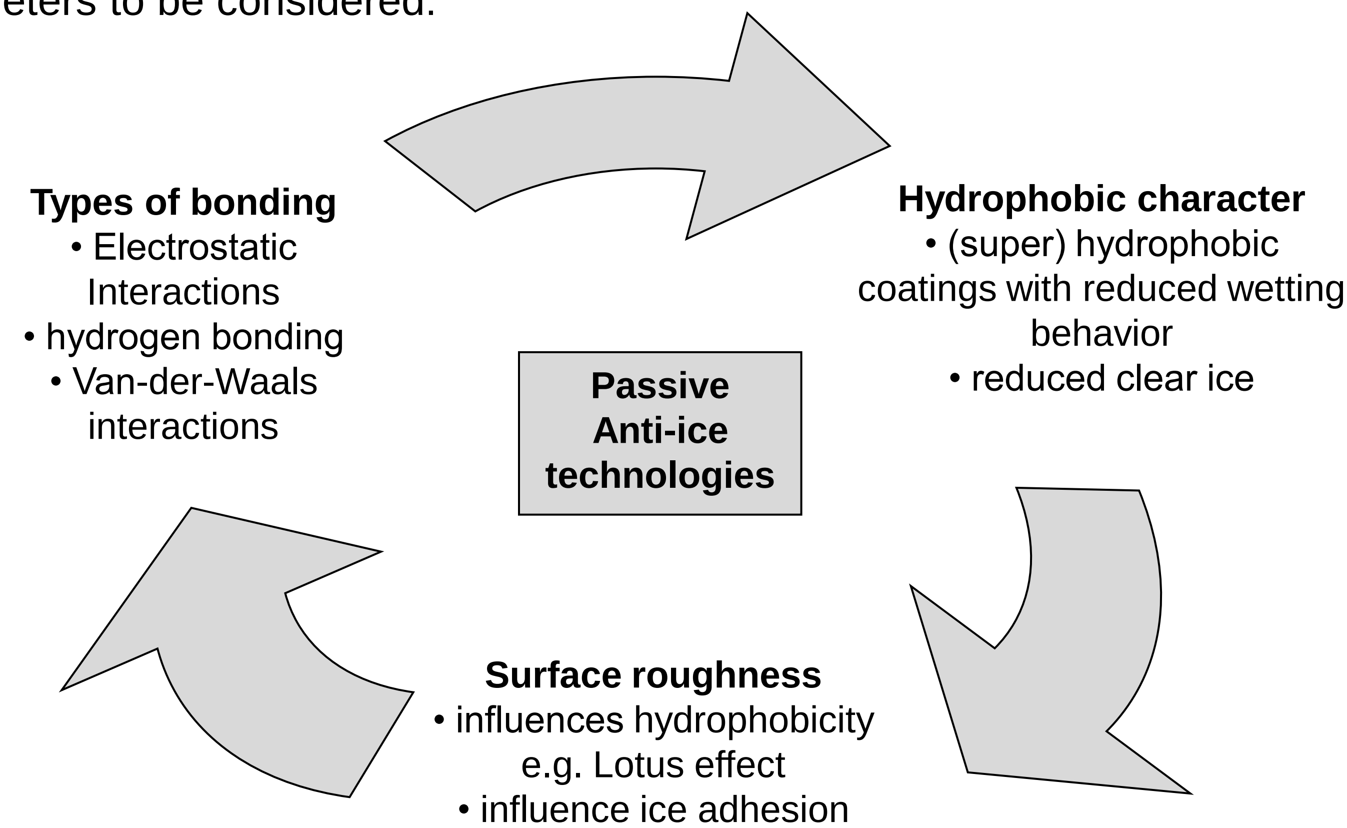
Ice adhesion reduction and wetting minimisation

Key parameters to be considered:



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

Parameter	Unmodified top coat	Passive anti-ice coating
Water contact angle [°]	82	124
Roughness Ra [µm]	0.17 (±0.01)	0.64 (±0.07)
Pictures of the ice rain test		
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	

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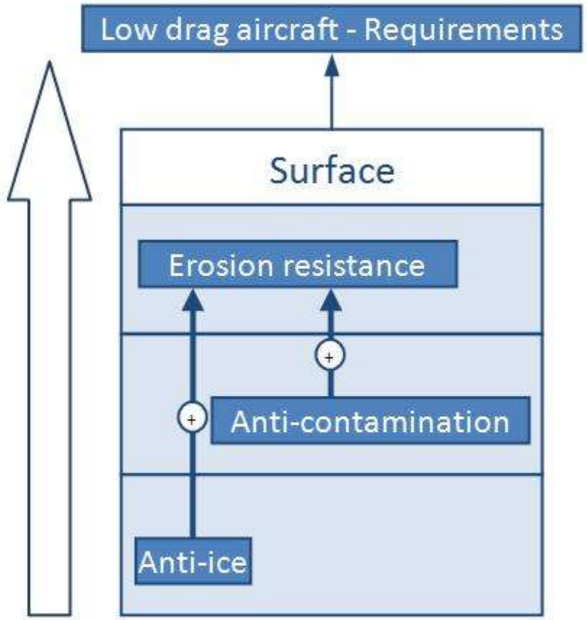
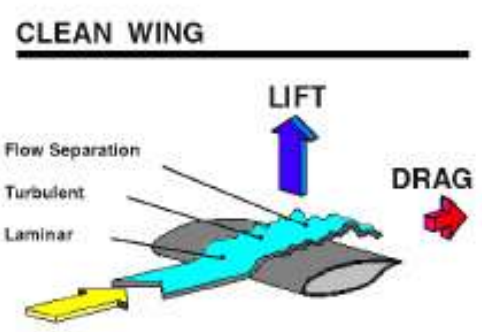
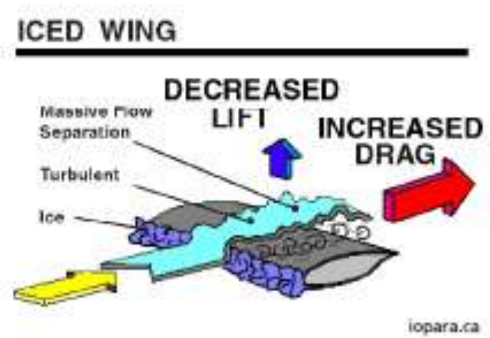
Technical demands on the coating „JTI project Clean Sky“



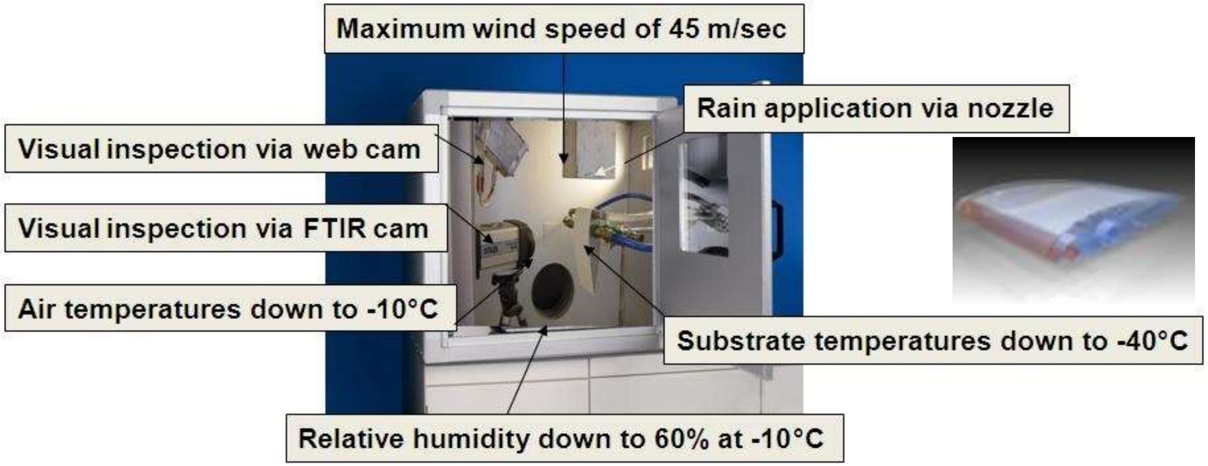
United states NAVI trainings film
Ice Formation On Aircraft (1961)





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

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



Runback ice formation

Development of test design with wing profile to

- **simulate ice accretion on leading edge and**
- **subsequent melting of ice, including 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**

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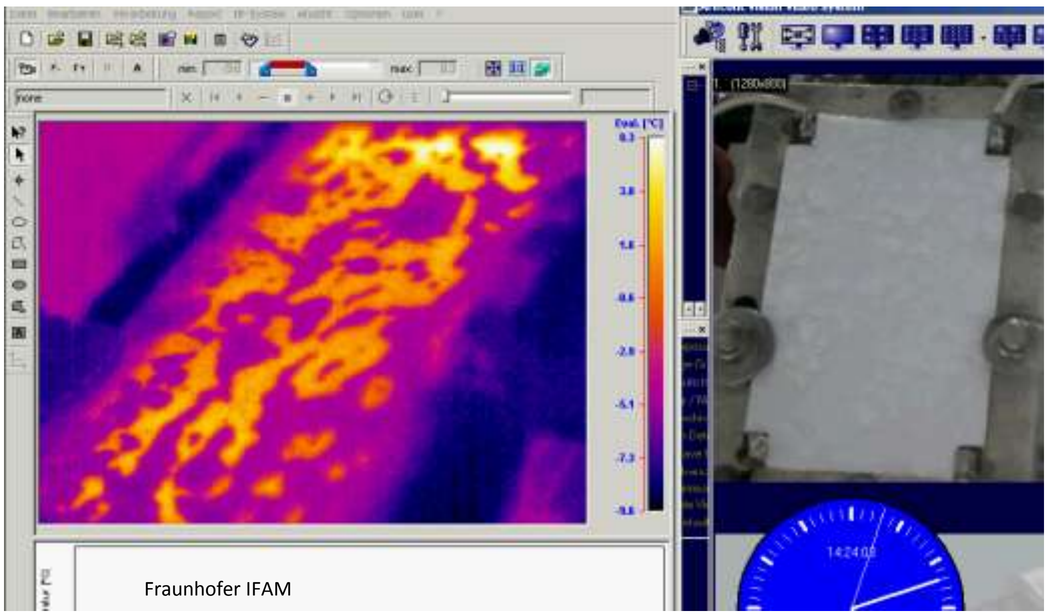
Investigation in electrically heated coatings

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.
Its using carbon nanotubes and graphite, a thin layer of electrically conductive material.



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

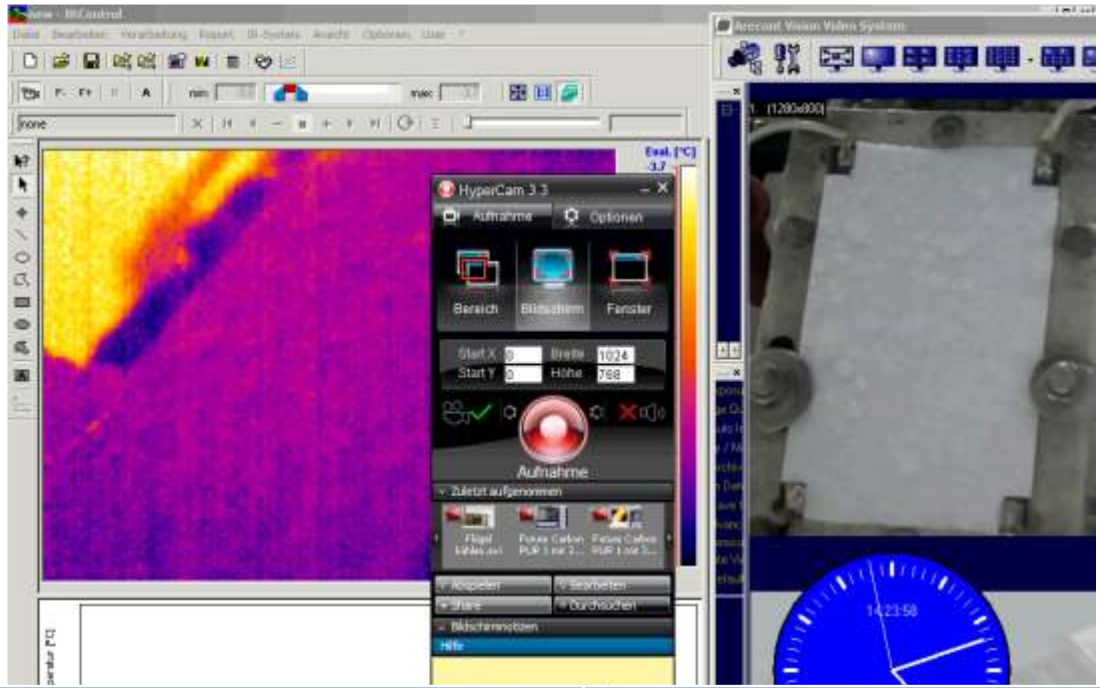
Spray applicability
to curved geometries and surfaces.

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

Targests:
- Improved aircraft safety
- reduced energy consumption



Resistance [Ω]	Type of coating / heating layer		Time de-icing -10°C-> 5°C [sec]
3.5	Al 2024 Plated with coatable foil	Carbo e-Therm	5

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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

<u>**Our next steps are:**</u>

- **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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