TAMPERE UNIVERSITY OF TECHNOLOGY

UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

Research on icing behavior and ice adhesion testing of icephobic surfaces

Christian Stenroos[1], Heli Koivuluoto[1], Giovanni Bolelli[2], Riku Ruohomaa[1], Luca Lusvarghi[2], Petri Vuoristo[1]

[1]Tampere University of Technology (TUT), Department of Materials Science, Tampere, Finland,

[2]University of Modena and Reggio Emilia (UNIMORE), Department of Engineering “Enzo Ferrari”, Modena ,Italy

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16TH INTERNATIONAL WORKSHOP ON ATMOSPHERIC ICING OF STRUCTURES

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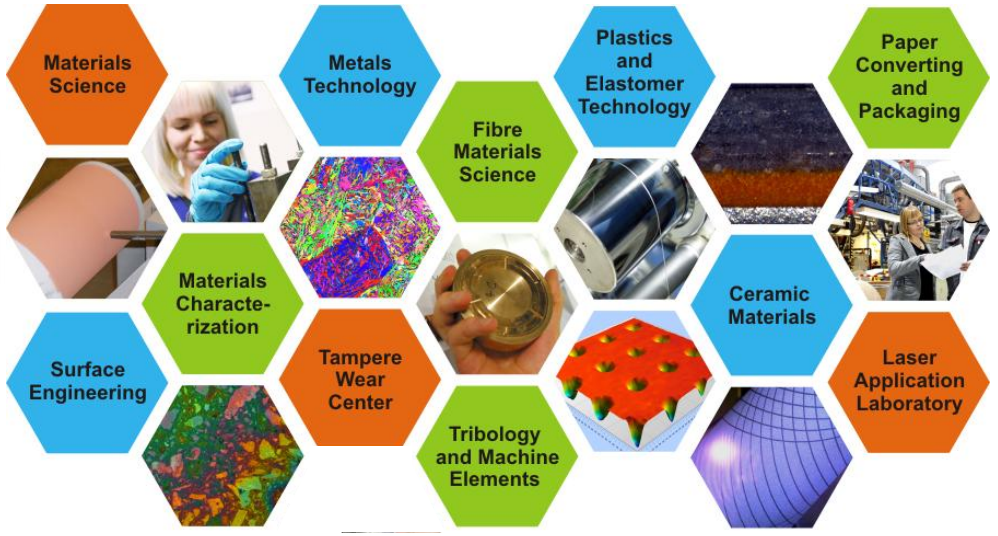
Tampere University of Technology (TUT)

- Established in 1965
- Started operating in the form of a foundation in 2010
- ~10,000 students, ~2,000 employees
- Collaborates with 230 universities around the world
- Quality assurance system audited by The Finnish Higher Education Evaluation Council in 2014

TAMPERE UNIVERSITY OF TECHNOLOGY

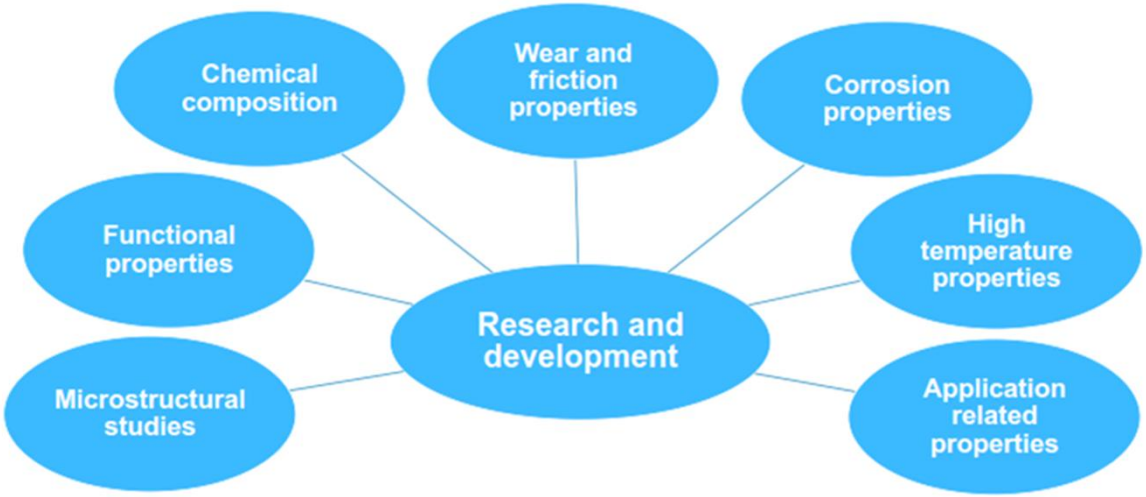
Department of Materials Science (DMS)

- Internationally high-level know-how on all materials based on strong interdisciplinary basic research
- 9 professors: Metals, Ceramic Materials, Plastics and Composites, Fibre Materials, Paper and Packaging, Characterization, Tribology and Machine Elements and **Surface Engineering**

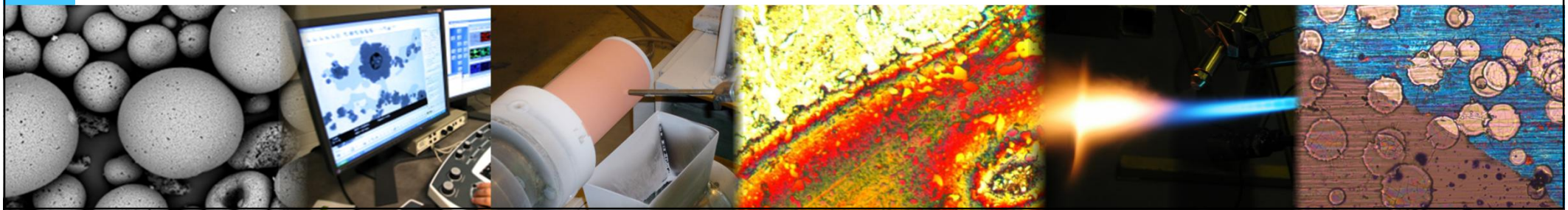


Laboratory of Surface Engineering

- Prof. Petri Vuoristo
- Personnel 15-20



- ***Research topics***
  - Thermal spraying (Thermal Spray Center Finland, TSCF)
  - Thin film technologies
  - Laser processing (Laser Application Laboratory, LAL)
  - **Icephobic coatings and surfaces (since 2013)**
  - Characterization and testing



Aim of work

Simulation of real icing conditions

- Ice accretions in icing wind tunnel
- Ice formation from microdroplets

Accretion of different ice types

- Glaze and rime ice

Behavior of different surfaces in icing conditions

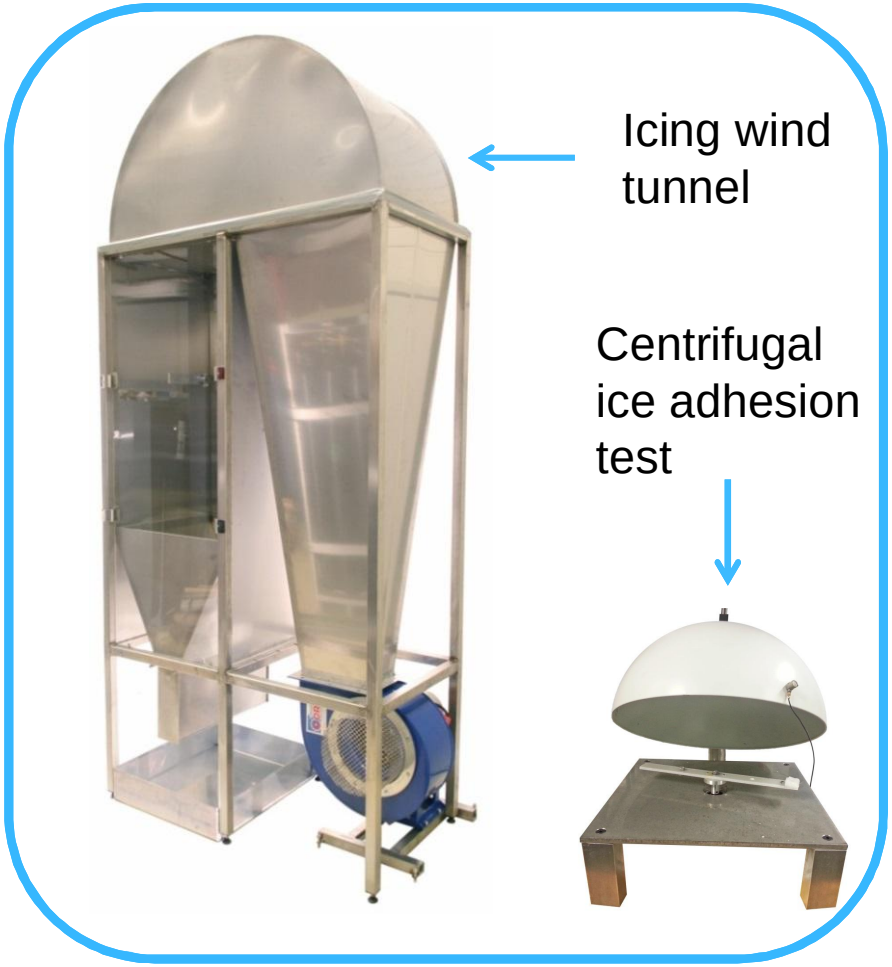
- Wettability, surface roughness and material differences

Measurement of ice adhesion

- Connections to CA, CAH and surface roughness

Testing equipment: Icing wind tunnel & Centrifugal ice adhesion test

Located in the climatic room



Testing equipment: Icing wind tunnel & Centrifugal ice adhesion test

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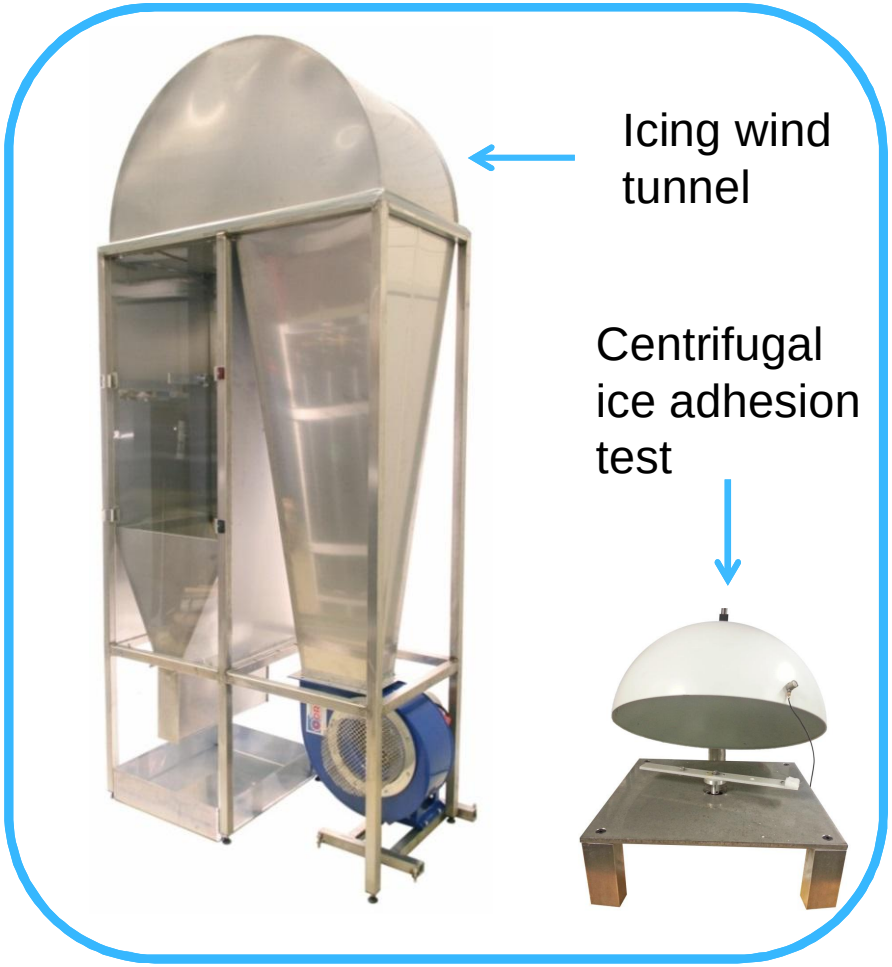
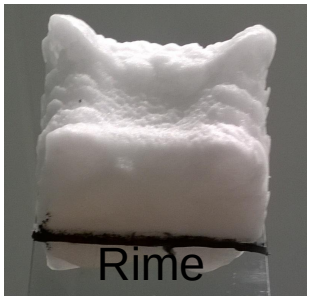


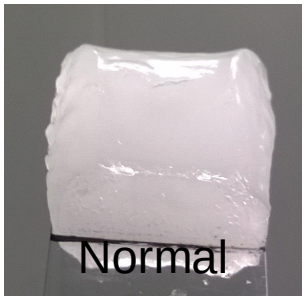
- Based on the description of Laforte & Beisswenger (ref1)
- Centrifugal force, provides shear stress, on the interface.
- Mass of the ice block is weighted and area of detached ice is measured
  → Maximum adhesive shear strength can be calculated

Ref1. C. Laforte, A. Beisswenger, Icephobic Material Centrifuge Adhesion Test, International Workshop on Atmospheric Icing of Structures (IWAIS) XI, Montreal, June 2005, 4 p.

Icing wind tunnel: Parameters & Ice types

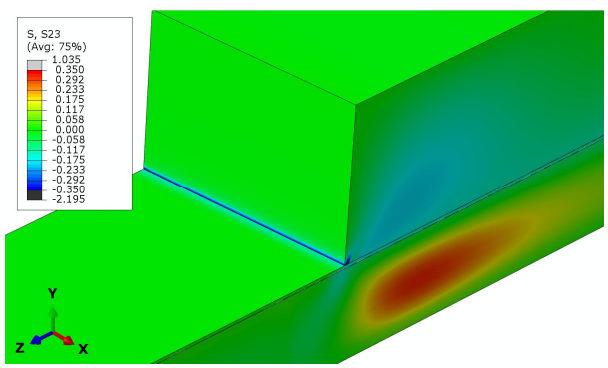
Parameter	Variable	Min	Max	Unit
Nozzle parameters	P (Liquid)	0	6	bar
	Q (Liquid)	0	0.3	l/min
	P (Gas)	0	6	bar
	Q (Gas)	0	150	l/min
Volume median diameter	D(V0,5)	25	1000	µm
Flow velocity	V	0	25	m/s
Temperature	T	0	-40	° C
Nozzle-specimen distance	H	0	1.9	m
Liquid water content	LWC	0	4.2	g/m^3
Number of sample		0	9	pcs

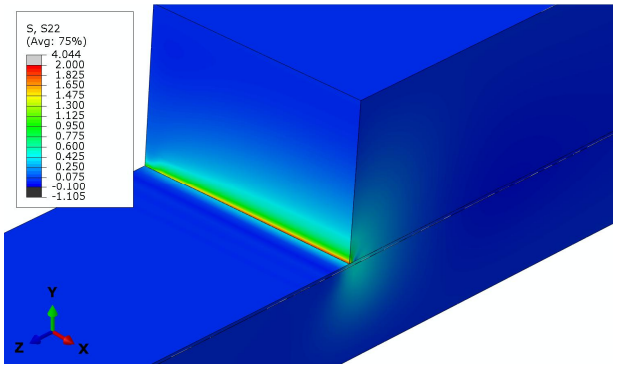




Centrifugal ice adhesion test: Operating principle & modelling

- Constant acceleration rate of 300 rpm/s untill ice detaches
- Ice detachment is observed with acceleration sensor





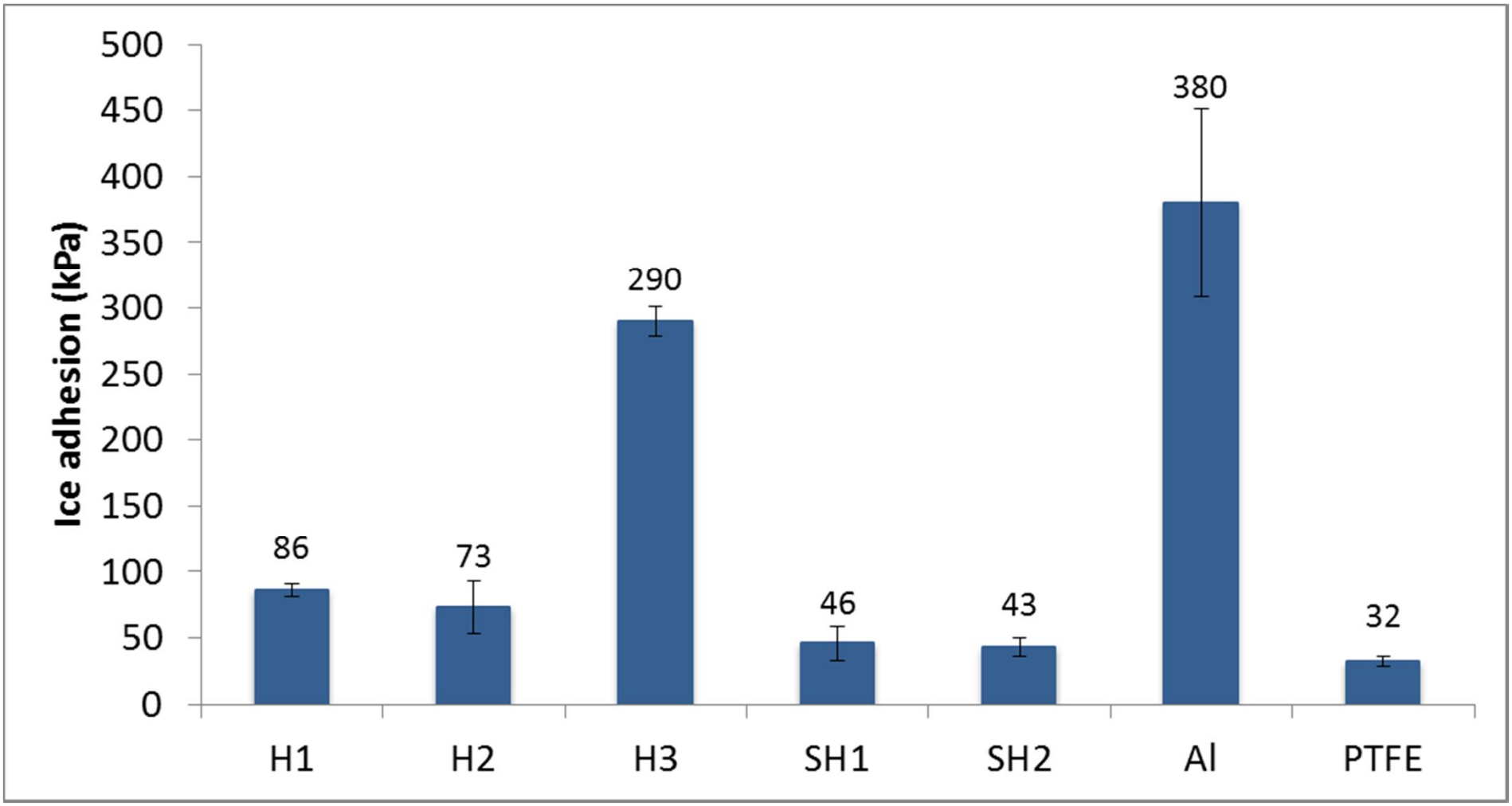
Materials and test methods

Sample	Coating/surface
H1	PTFE-based hydrophobic coating, Alu Releco (FIN)
H2	FEP-based hydrophobic coating, Alu Releco (FIN)
H3	PTFE-based hydrophobic coating, CeraFlon, Alu Releco (FIN)
SH1	F-containing superhydrophobic hybrid coating, Millidyne (FIN)
SH2	Superhydrophobic coating, Ultra-Ever Dry®
Al	Reference: Polished aluminium bulk surface
PTFE	Reference: PTFE- tape, smooth surface

Substrate: Polished stainless steel

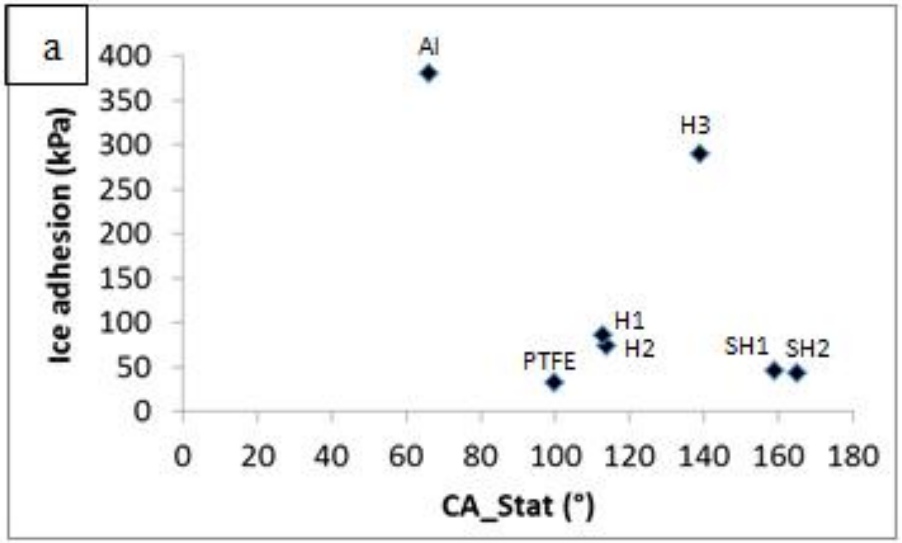
Testing method	Measured variable
Contact angle measurement	Static and dynamic contact angles
Optical profilometer	3D-surface profiles, R_a and S_a
Centrifugal ice adhesion	Maximum shear adhesion strength

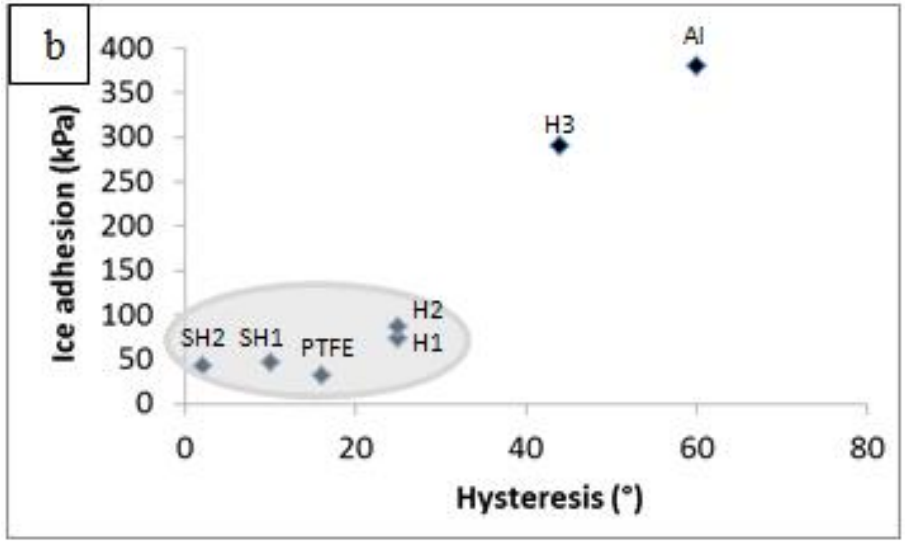
Results: Ice adhesion



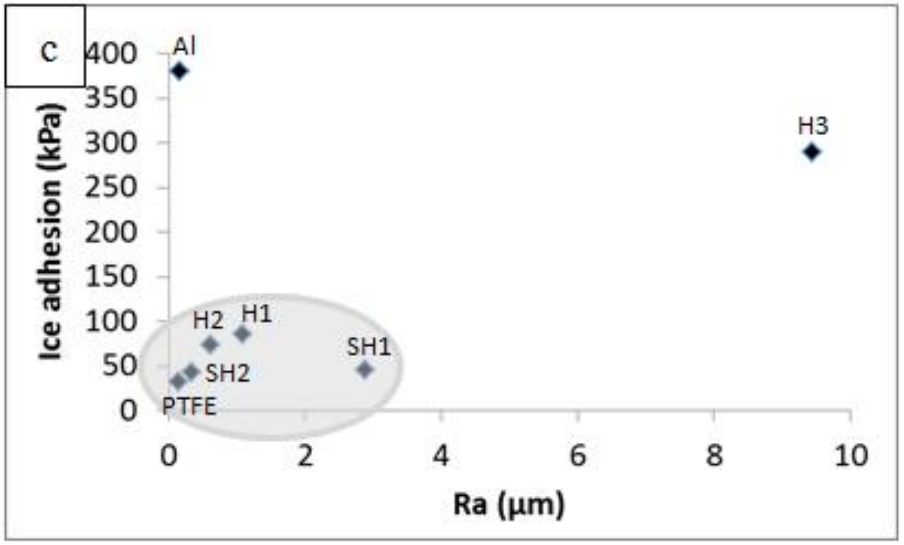
Wetting behaviour vs. Ice adhesion

Ice adhesion increases ↓	Sample	CA_Stat (°)	CA_Adv (°)	CA_Rec (°)	Hysteresis (°)
	PTFE	100	108	92	16
	SH2	165	166	164	2
	SH1	159	165	155	10
	H2	114	123	98	25
	H1	113	116	91	25
	H3	139	148	104	44
	Al	66	80	20	60
Superhydrophobic		Hydrophobic		Hydrophilic	

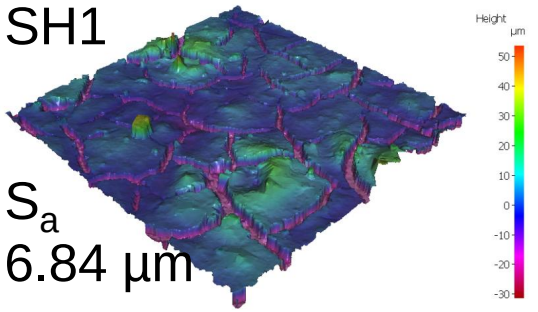




Surface roughness vs. Ice adhesion

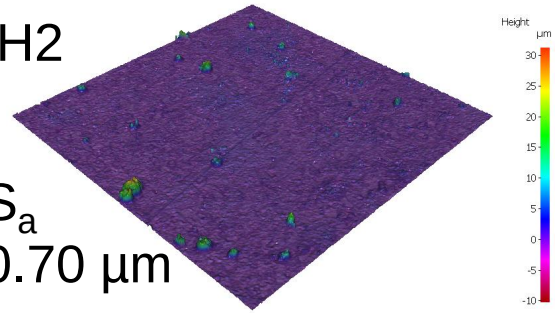


SH1



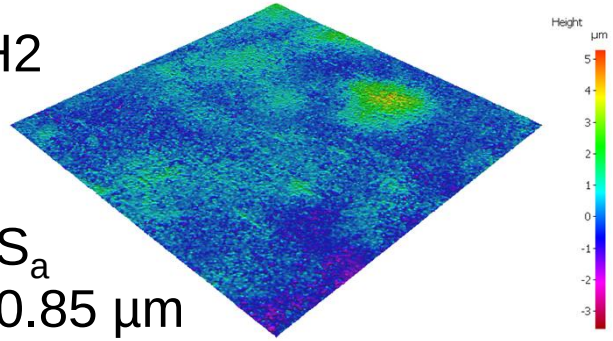
S_a 6.84 µm

SH2



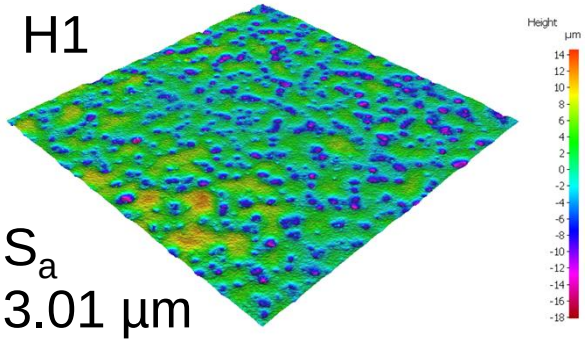
S_a 0.70 µm

H2



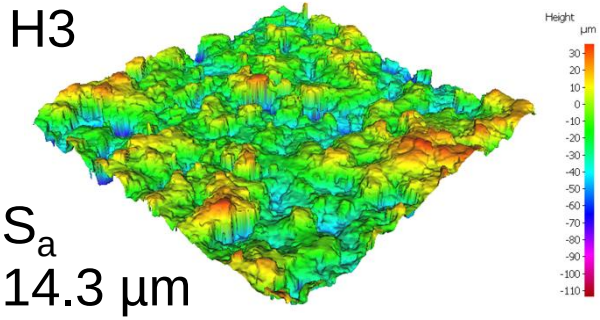
S_a 0.85 µm

H1



S_a 3.01 µm

H3



S_a 14.3 µm

Conclusions

- Different ice types were created
  - Glaze and rime ice
- One factor alone can not explain ice adhesion behavior
  - Combination of surface roughness, wetting behavior and surface chemistry
- Next steps
  - Wear resistance vs. ice adhesion
  - Effect of different icing conditions