Interlaboratory study of ice adhesion using different techniques

Supplementary materials

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S1. Experimental protocol

Table S1 Experimental protocol used for the interlaboratory study. See Experimental section for more info on procedures.

Facility	Ice type	Surface #	Temperature	Repetitions	Icing time	Waiting time
AMIL	Precipitation ice	Aluminum	-10	6	33min	1h
AMIL	Precipitation ice	Coating	-10	6	33min	1h
AMIL	Precipitation ice	Aluminum	-18	6	33min	1h
AMIL	Precipitation ice	Coating	-18	6	33min	1h
AMIL	Bulk water ice	Aluminum	-10	6	3h	15min
AMIL	Bulk water ice	Coating	-10	6	3h	15min
AMIL	Bulk water ice	Aluminum	-18	6	3h	15min
AMIL	Bulk water ice	Coating	-18	6	3h	15min
NTNU	Bulk water ice	Aluminum	-10	5	3h	15min
NTNU	Bulk water ice	Coating	-10	5	3h	15min
NTNU	Bulk water ice	Aluminum	-18	5	3h	15min
NTNU	Bulk water ice	Coating	-18	5	3h	15min

Notes

- Temperature relates to both freezing temperature and testing temperature
- Initial temperature of both surfaces and water was room temperature for bulk water ice
- All surfaces were only tested once

S2. All experimental results

Table S2 Experimental results from the ice adhesion tests for all 66 samples.

Surface		**Aluminum**	**Aluminum**	**Coating**	**Coating**
Temperature		T_{air} = -10°C	T_{air} = -18°C	T_{air} = -10°C	T_{air} = -18°C
AMIL, precipitation ice	1	727	265	81	62
	2	741	320	79	81
	3	782	387	84	90
	4	788	346	85	59
	5	774	344	81	83
	6	589	380	86	90
	Mean	**734**	**340**	**83**	**78**
	SD	**75**	**44**	**3**	**14**
		10 %	**13 %**	**4 %**	**18 %**
AMIL, bulk water ice	1	343	269	118	139
	2	346	315	70	119
	3	281	318	39	39
	4	332	193	113	17
	5		294	127	121
	6		318	106	72
	Mean	**326**	**285**	**96**	**85**
	SD	**30**	**49**	**34**	**49**
		9 %	**17 %**	**36 %**	**58 %**
NTNU, bulk water ice	1	375	338	118	182
	2	543	467	96	158
	3	405	257	134	143
	4	819	569	119	97
	5	402	332	88	96
	Mean	**509**	**393**	**111**	**135**
	SD	**185**	**124**	**19**	**38**
		36 %	**32 %**	**17 %**	**28 %**

S3. Ice formation

The formation of bulk water ice is illustrated in Figures 1, 2 and 3 for AMIL and NTNU, respectively. For the generation of precipitation ice, we refer to other publications [1, 2].

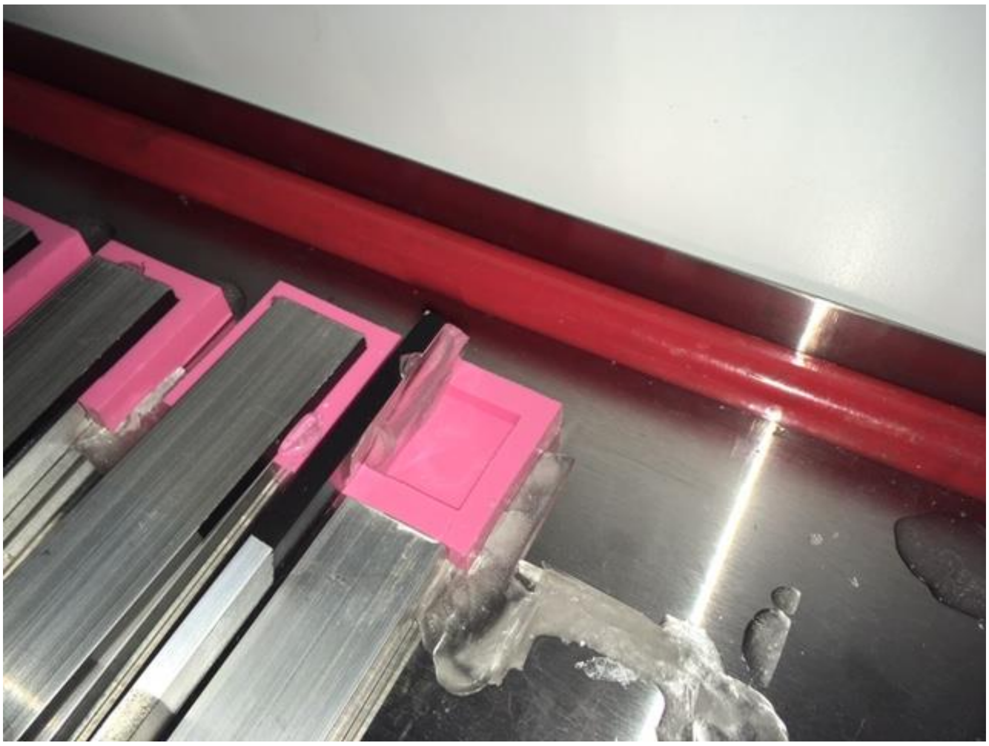

Figure S1 Formation of bulk water ice at AMIL, same procedure for both temperatures.

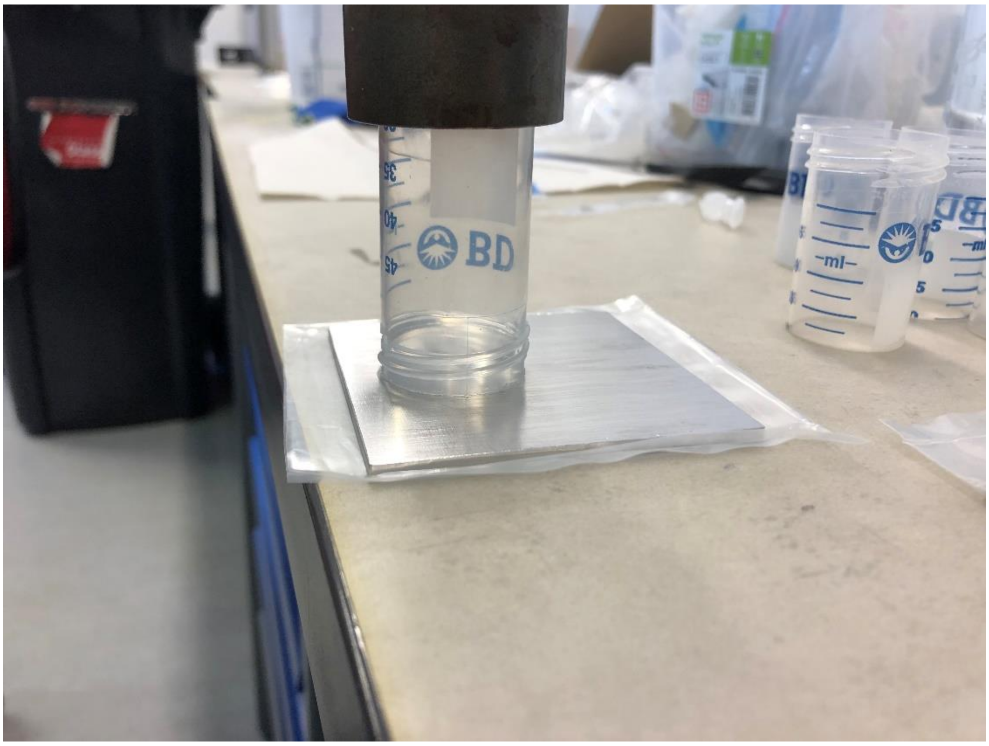

Figure S2 Formation of bulk water ice on aluminum surface at NTNU. For T_{air} = -18°C, the water was added in room temperature and moved to the freezer. For -10°C, the water insertion was performed in a cold room, otherwise with the same procedure.

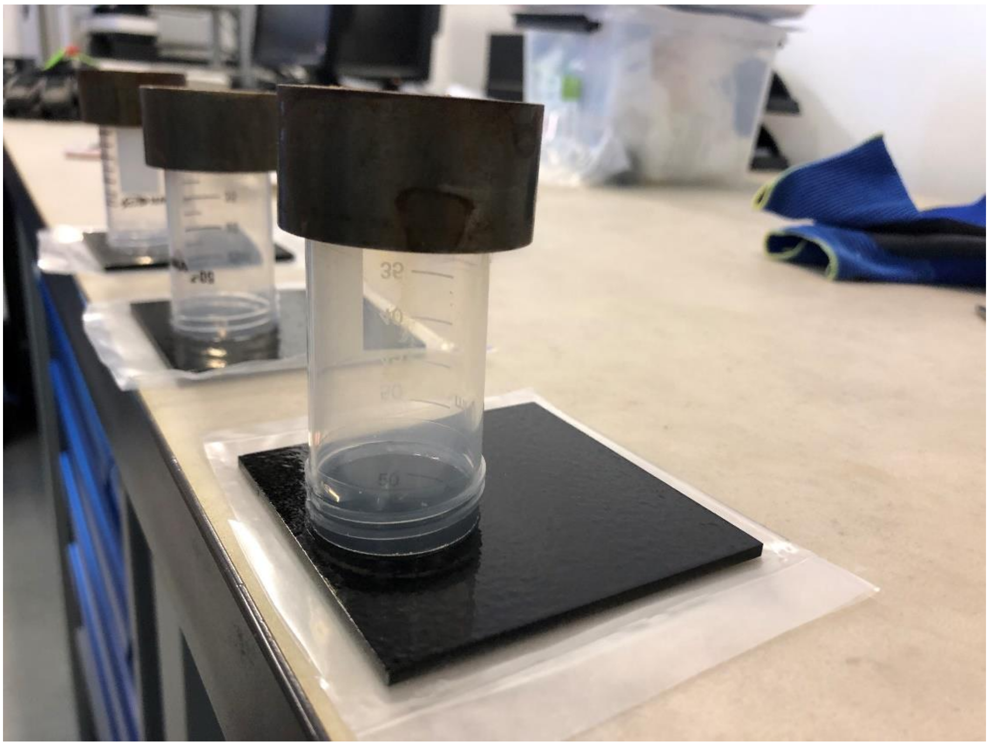

Figure S3 Formation of bulk water ice on icephobic coating at NTNU, similar to Figure 2.

S4. Typical failure modes

Typical failure modes when testing ice adhesion strength can be seen in Figures 4-12. For bulk water ice, the failures were adhesive. For precipitation ice at AMIL, the failures were mostly adhesive at T_{air} = -10°C and cohesive at T_{air} = -18°C.

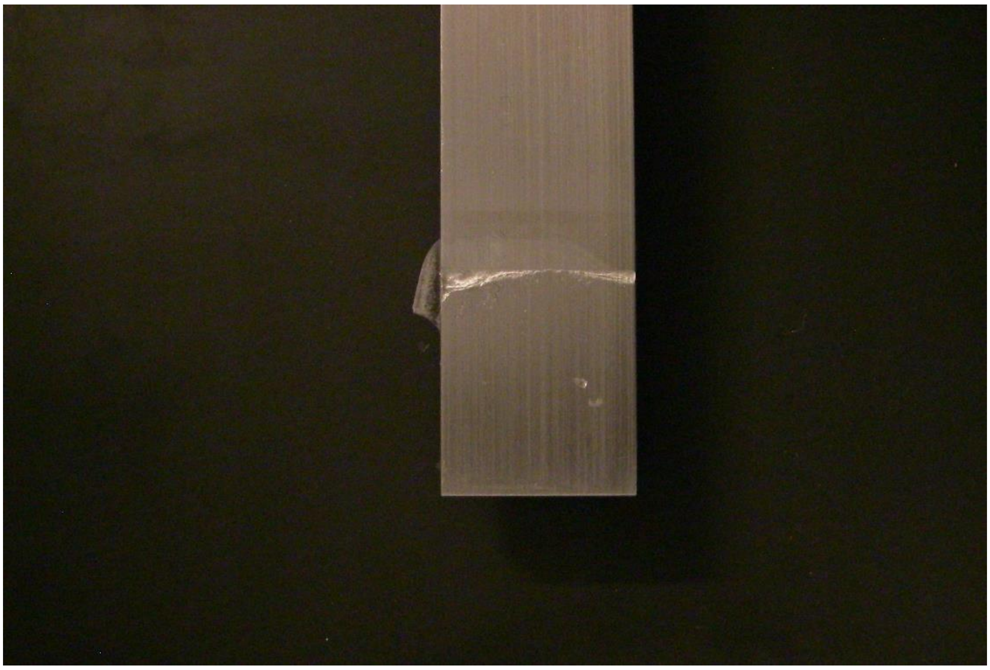

Figure S4 Typical adhesive failure observed at AMIL for bulk water ice at both temperatures, here for aluminum surface.

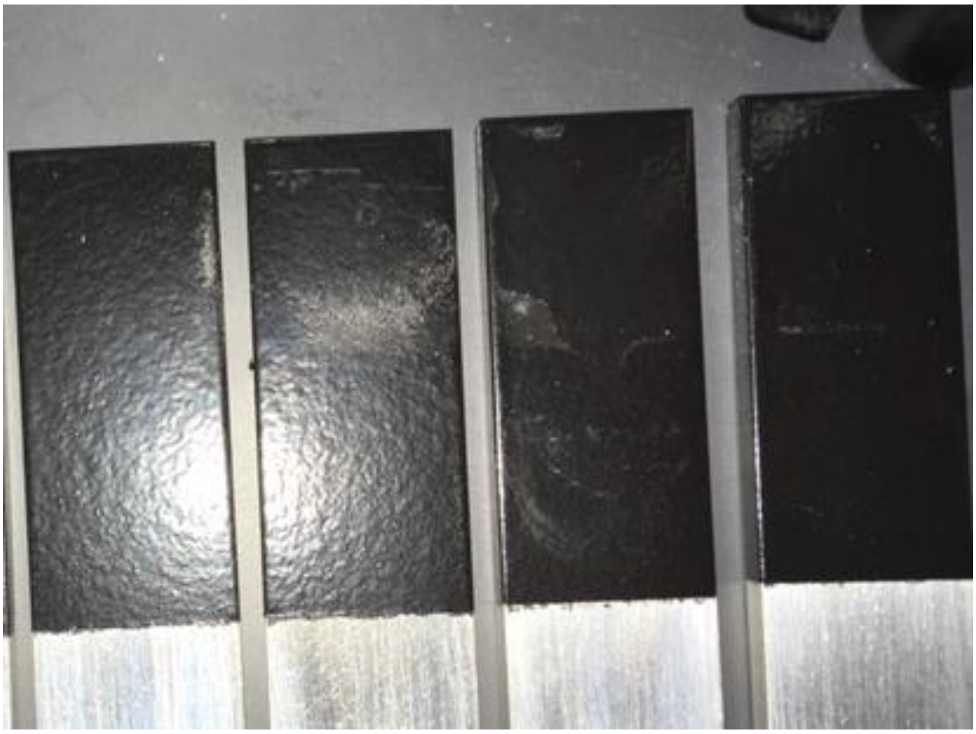

Figure S5 Typical adhesive failure observed at AMIL for bulk water ice at both temperatures, here for the icephobic coating.

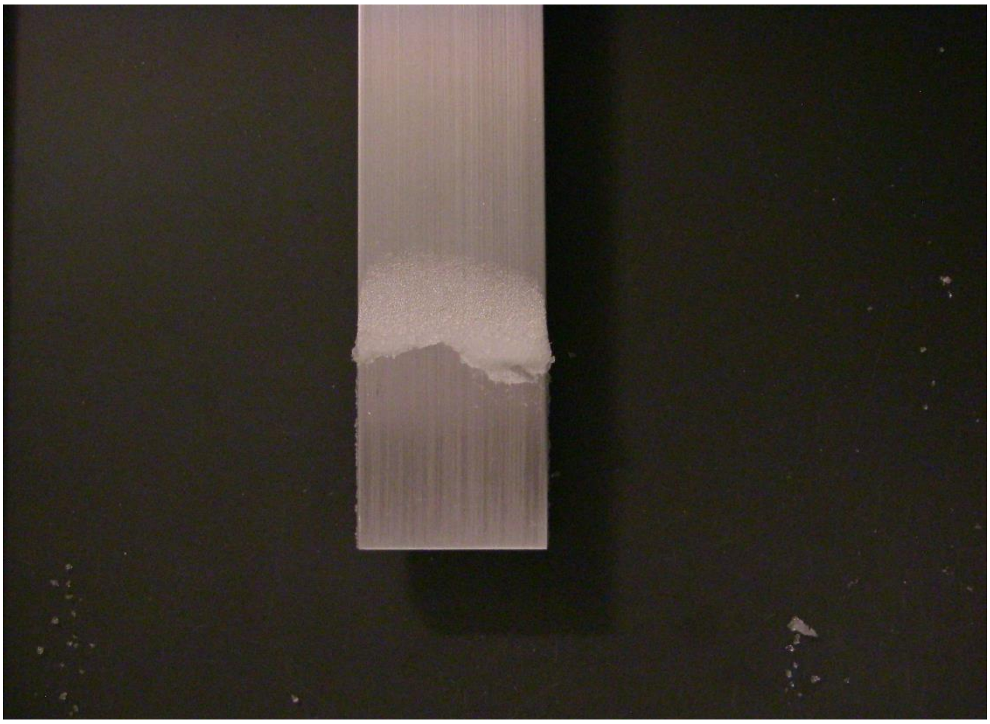

Figure S6 Adhesive failure observed at AMIL for precipitation ice at T_{air} = -10°C, here for aluminum surface.

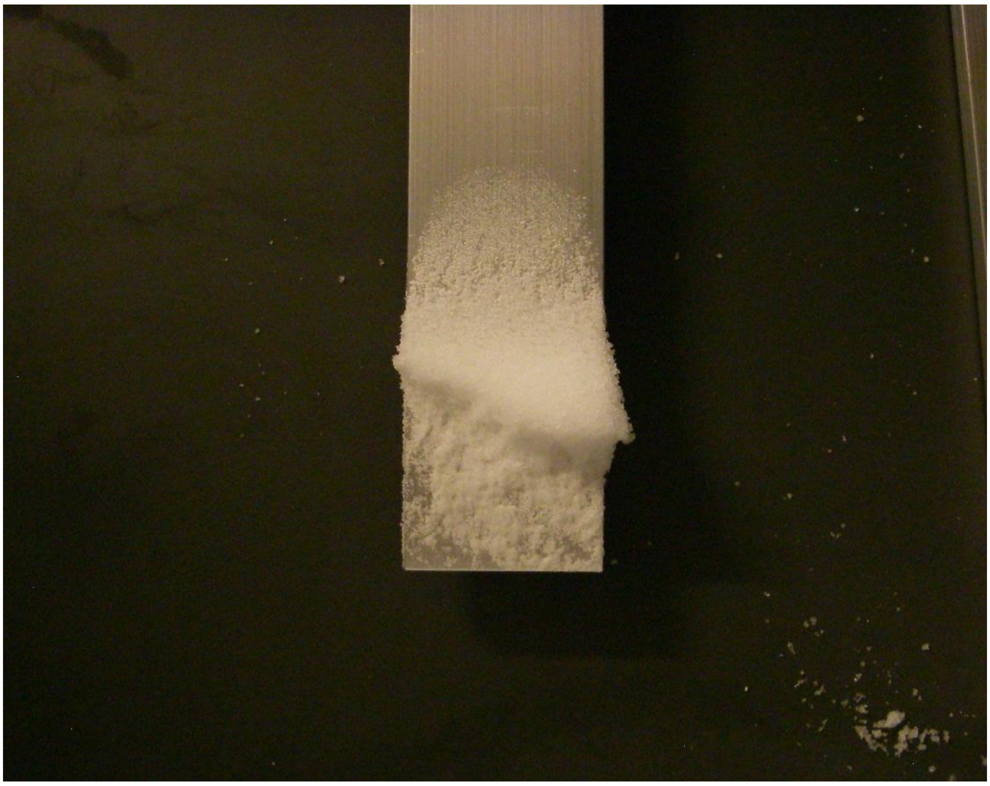

Figure S7 Cohesive failure observed at AMIL for precipitation ice at T_{air} = -18°C, here for aluminum surface.

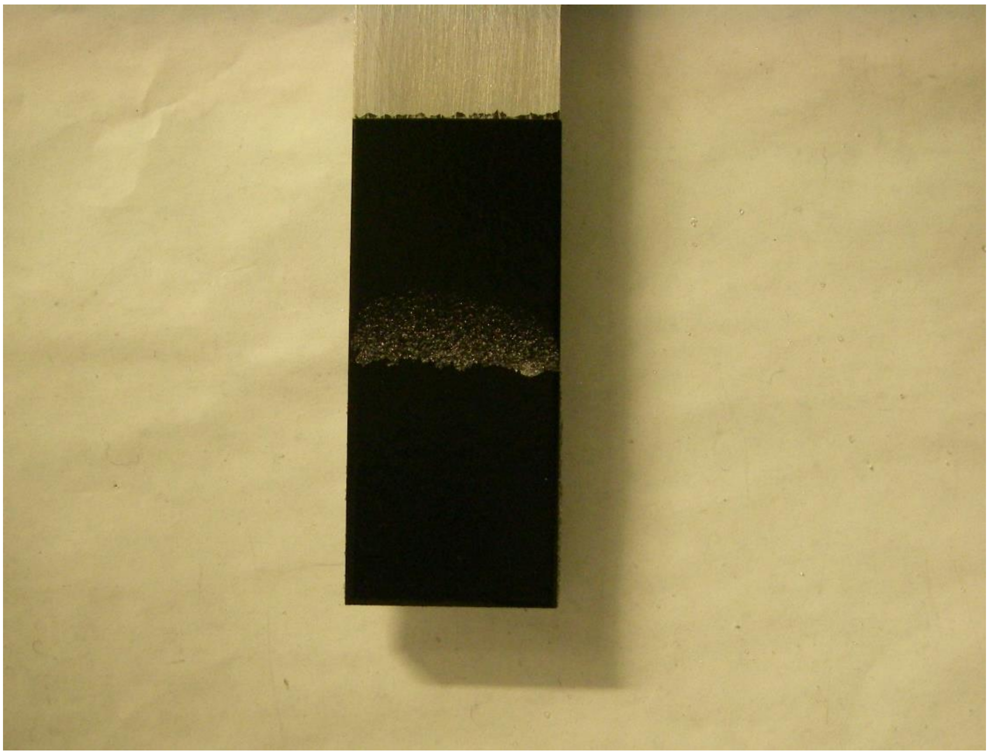

Figure S8 Adhesive failure observed at AMIL for precipitation ice at T_{air} = -10°C, here for icephobic coating.

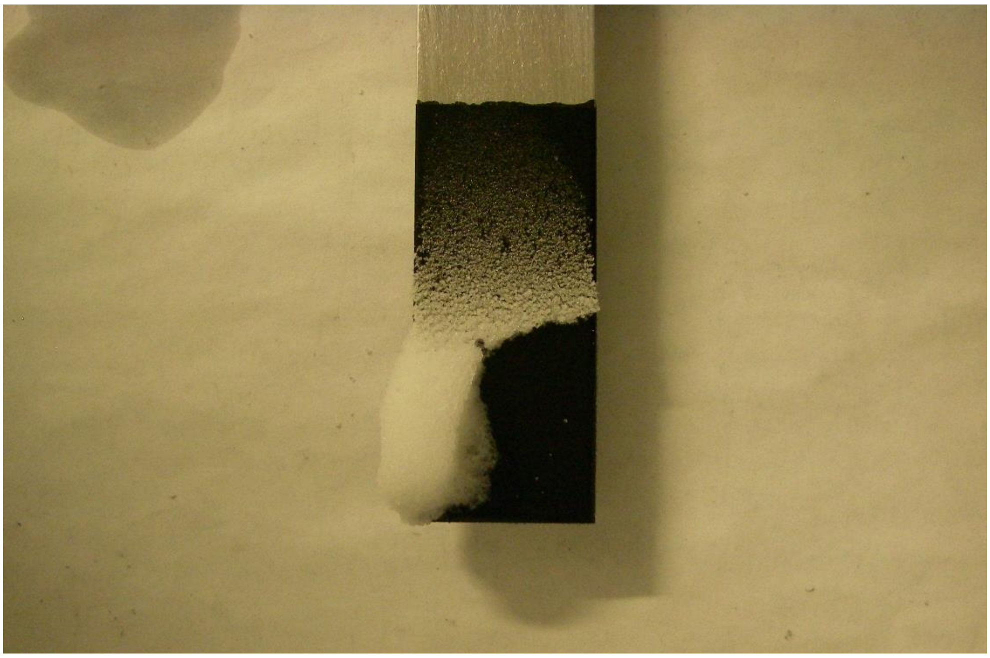

Figure S9 Cohesive failure observed at AMIL for precipitation ice at T_{air} = -18°C, here for icephobic coating.

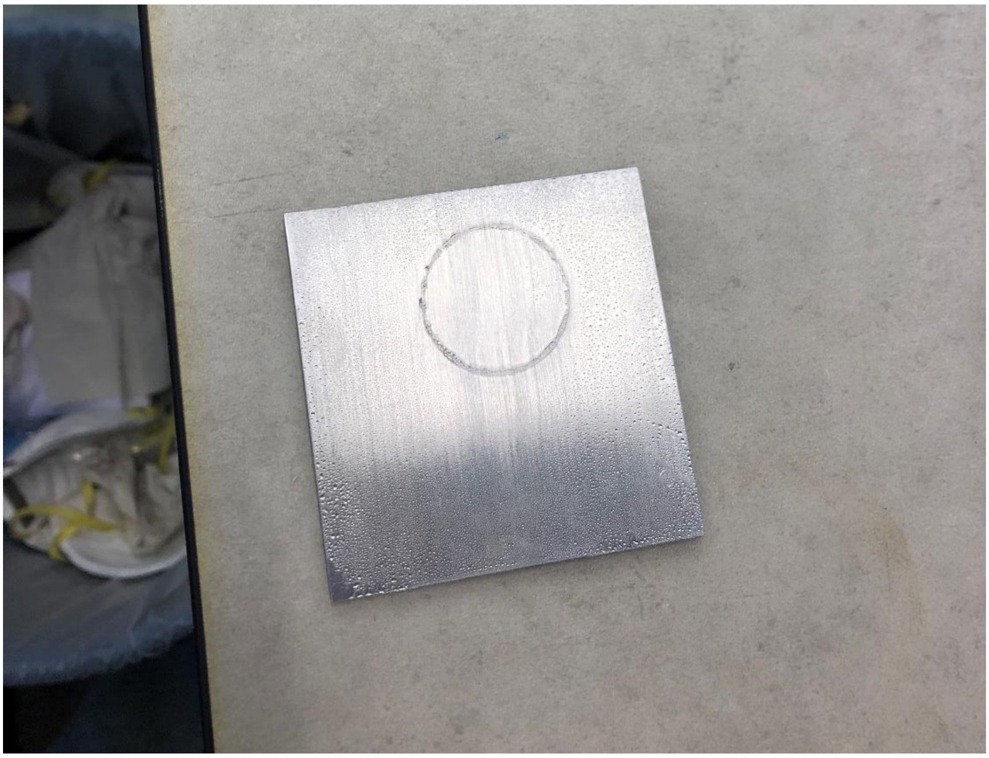

Figure S10 Typical adhesive failure at ice detachment for tests performed at NTNU. Here for aluminum surface tested at T_{air} = -18°C.

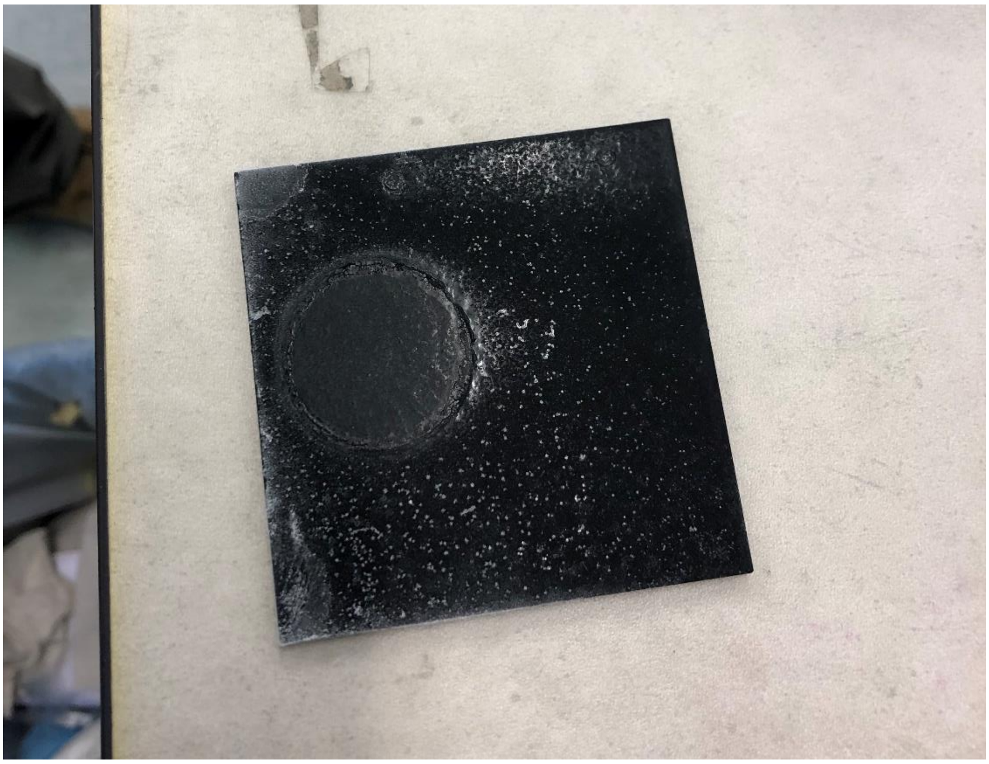

Figure S11 Typical adhesive failure at ice detachment for tests performed at NTNU. Here for icephobic surface tested at T_{air} = -18°C.

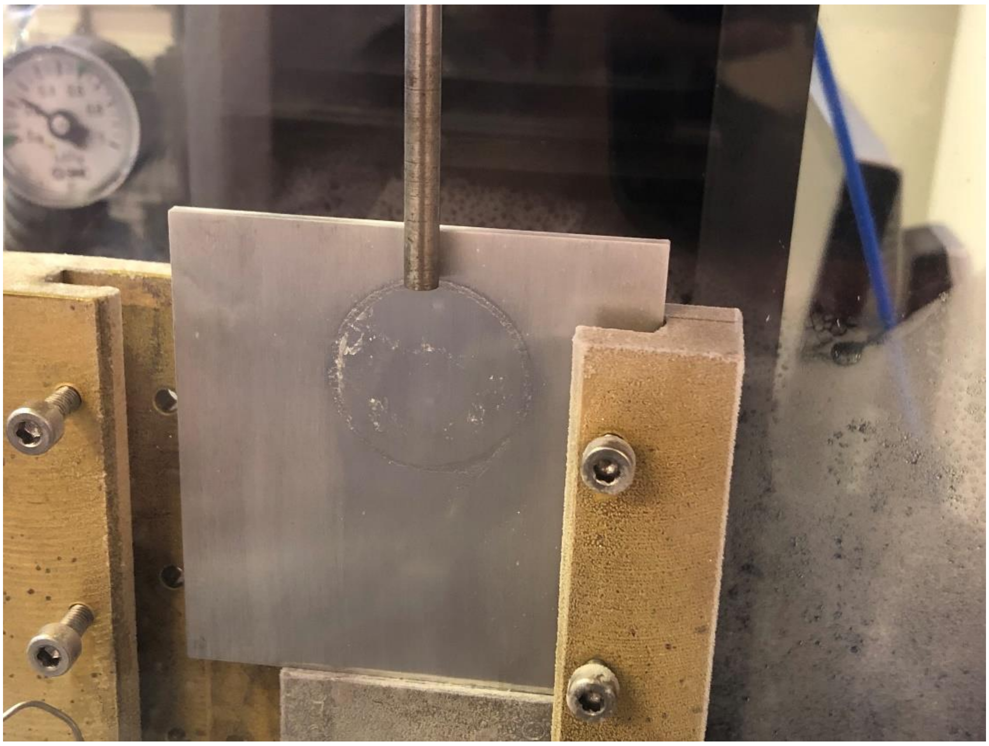

Figure S12 Picture of the only cohesive failure observed for tests at NTNU. This failure occurred for aluminum surface at T_{air} = -10°C.

S5. Adhesion reduction factor (ARF)

The Adhesion reduction factor (ARF) is defined as the ratio of the ice adhesion strength of a reference material, often aluminum, to the ice adhesion strength of the coating being tested [3]. If the ARF is above 1, the coating has an improved anti-icing behavior. The ARF for the coating tested in this study is shown in Figure 13 for all configurations of ice type and laboratory. The discussion of the ARF is left for a later publication.

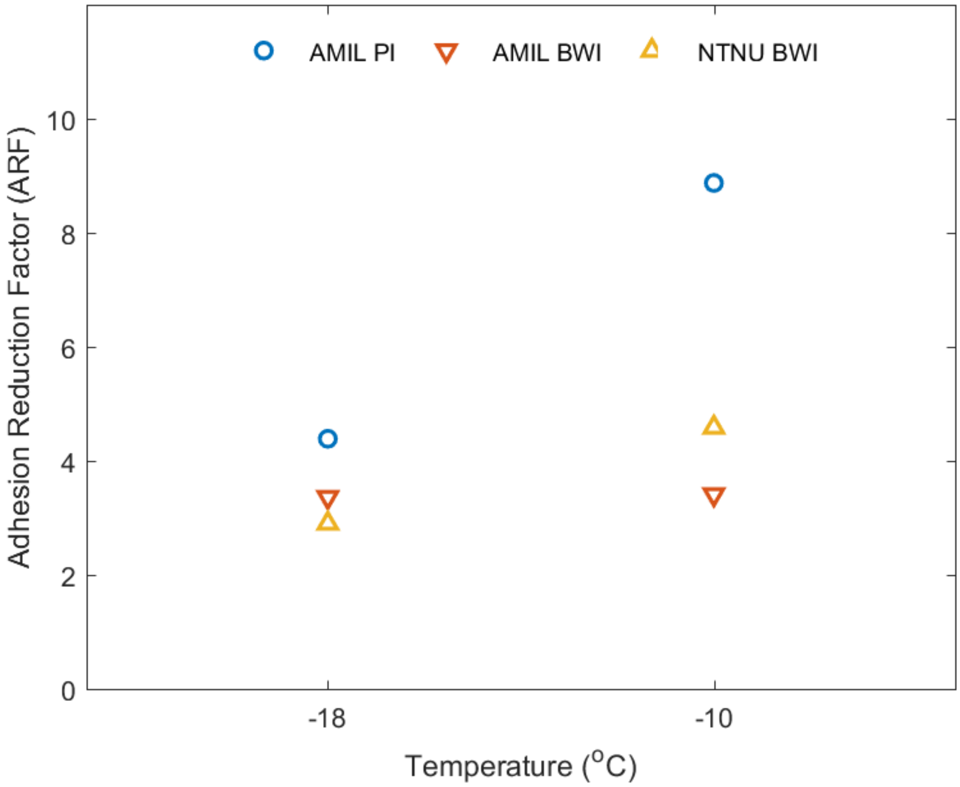

Figure S13 Overview of ARF for the three ice types for both temperatures.

References

1. Laforte, C. and A. Beisswenger. *Icephobic Material Centrifuge Adhesion Test*. in *11th International Workshop on Atmospheric Icing on Structures (IWAIS)*. 2005. Montral, Canada.
2. Guerin, F., et al., *Analytical model based on experimental data of centrifuge ice adhesion tests with different substrates.* Cold Regions Science and Technology, 2016. **121**: p. 93-99.
3. Brassard, J., et al., *Icephobicity: Definition and Measurement Regarding Atmospheric Icing*, in *Advances in Polymer Science*. 2017, Springer: Berlin, Heidelberg.