Anti-icing liquid-infused coating for wind turbines

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Supporting information

Table S1. Electrospinning and electrospray process parameters

	PECA membrane	PVDF-HFP membrane	PECA/PVDF-HFP membrane
Process	Electrospinning	Electrospinning	Electrospinning
Needle	20G	21G-08 bended	21G-08 bended
Voltage [kV]	18	18	18
Trip lenght [mm]	35	35	35
Trip speed [mm/s]	30	30	30
Distance col-needle [cm]	15-16	15-16	15-16
Collector speed [rpm]	100	100	100
Flow [mL/h]	3	1.5	1.5

Table S2. Electrospinning and electrospray parameters to prepare BLIS coating

	Bi-layer liquid infused surface coating, BLIS		
	1) PVDF-HFP	2) Krytox lubricant	3) PECA/PVDF-HFP
Process	Electrospinning	Electrospray	Electrospinning
Needle	21G-08 bended	21G-08 bended	21G-08 bended
Voltage [kV]	18	25	18
Trip lenght [mm]	35	35	35
Trip speed [mm/s]	30	30	30
Distance col-needle [cm]	15-16	10	15-16
Collector speed [rpm]	100	100	100
Flow [mL/h]	1.5	1	1.5

Table S3. Roughness parameters of the surfaces after heat treatment.

Sample	Ra (µm)	Rq (µm)	Rt (µm)	Rsk	Rku
PECA fibers	4.12	5.12	29.37	1.59	3.03
PECA heated at 160 °C	0.76	0.95	5.15	1.59	2.95
PECA heated at 180 °C	0.84	1.12	7.12	1.86	4.21
PECA heated at 200 °C	0.49	0.63	3.63	1.71	3.49
PECA/PVDF-HFP fibers	1.91	2.39	12.90	1.66	3.38

PECA/PVDF heated at 160 °C	1.50	1.90	11.77	1.60	3.03
PECA/PVDF heated at 180 °C	1.28	1.65	10.80	1.75	3.74
PECA/PVDF heated at 200 °C	1.12	1.42	8.16	1.70	3.58
PVDF-HFP fibers	2.47	3.14	20.09	1.70	3.50
PVDF-HFP heated at 160 °C	2.63	3.34	16.43	1.64	3.19
PVDF-HFP heated at 180 °C	2.90	3.65	24.75	1.637	3.187
PVDF-HFP heated at 2000 °C	2.99	3.85	22.27	1.66	3.25

There are many parameters used to characterize rough surfaces. Arithmetical mean height (Ra) and root mean square height (Rq) are the most commonly used. They are related to distance to the different points to the mean line of the surface. Another of the most used parameters is the peak-valley distance (Rt) related with higher peaks and deepest valleys of the surface. Considering the wettability properties, the Skewness (Rsk) and Kurtosis (Rku) parameters have proven to be relevant. In this sense, an Rsk parameter close to 0 indicates a greater homogeneity of the surface without large peaks and valleys that could favor pining phenomena. Rku parameter is a statistical parameter that expresses the concentration of data around the mean evaluating. A kurtosis with value of 3 describes a Gaussian distribution of amplitudes.

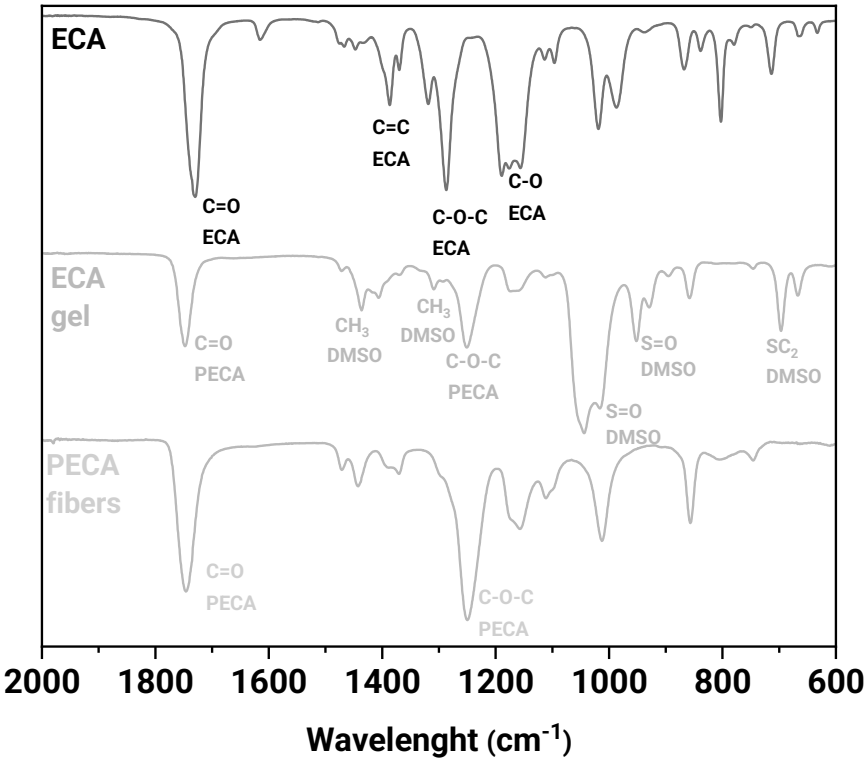


Figure S1. ATR-FTIR spectra of ECA monomer, the ECA-DMSO gel and the electrospun PECA fibers.

The polymerization of ECA to obtain PECA was studied by comparing the ATR-FTIR spectra of ECA monomer, the gel (containing ECA and DMSO) and the PECA fibers after electrospinning.

Bands assigned to the functional groups of the molecule of ECA can be identified in the spectrum (black line): the conjugated C=O stretching at 1730 cm^{-1}, the C=C stretching at 1615 cm^{-1}, conjugated C-O-C stretching modes at 1287 cm^{-1} and 1190 cm^{-1}. After mixing the ECA monomer with DMSO, typical bands of DMSO can be found: the CH_3 symmetrical bending at 1406 cm^{-1}, CH_3 umbrella mode at 1309 cm^{-1}, S=O stretching modes at 1047 cm^{-1} and 952 cm^{-1} and SC_2 asymmetric stretching at 697 cm^{-1}. Also, bands corresponding to saturated C=O and single saturated C-O-C can be seen at 1748 cm^{-1} and 1250 cm^{-1} respectively, shifted due to the polymer molecular environment. Finally, the IR spectrum of the electropun fibers consists of the typical vibrations of PECA without contributions of solvents (DMSO). Infrared analysis shown that DMSO initiates the polymerization of ECA monomers, leading to the formation of PECA polymer upon mixing. Following the electrospinning process, PECA fibers are obtained without any noticeable traces of remaining DMSO.

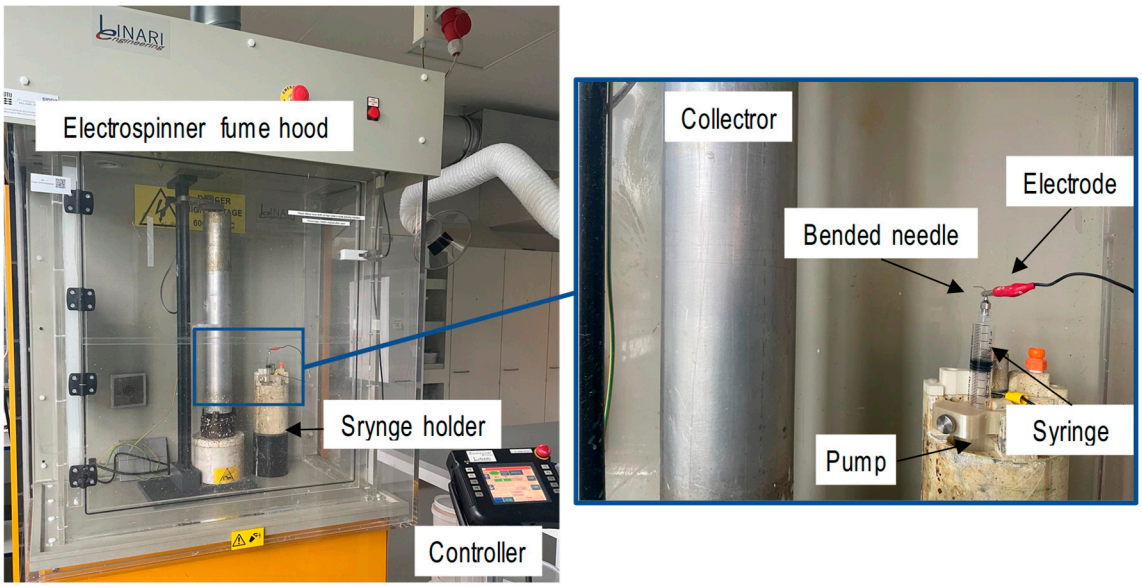


Figure S2. RT Advanced electrospinner by Linari engineering

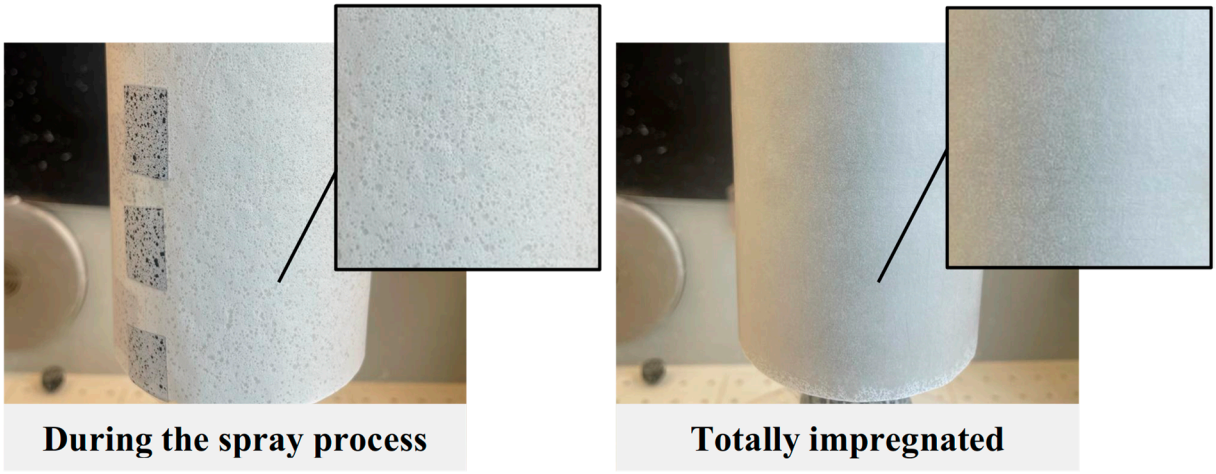


Figure S3. Electrospray process of the lubricant on the anti-wetting PVDF-HFP fibers

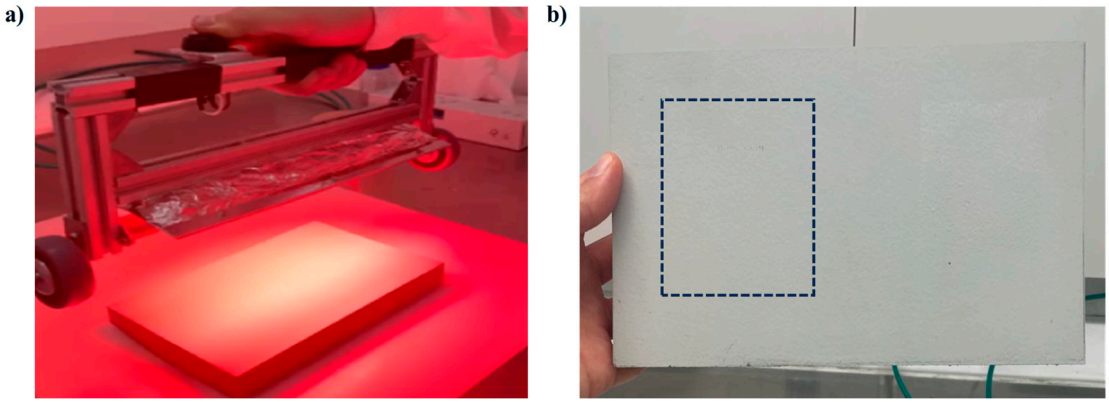


Figure S4. Adhesion of the coating to the wind turbine blade by heat applied by an infrared lamp (a) Infrared lamp used to apply heat for the adhesion of the LIS coating on the wind turbine blade (b) BLIS membrane adhered to an actual piece of wind turbine blade.



Figure S5. Set up for measuring ice adhesion strength.

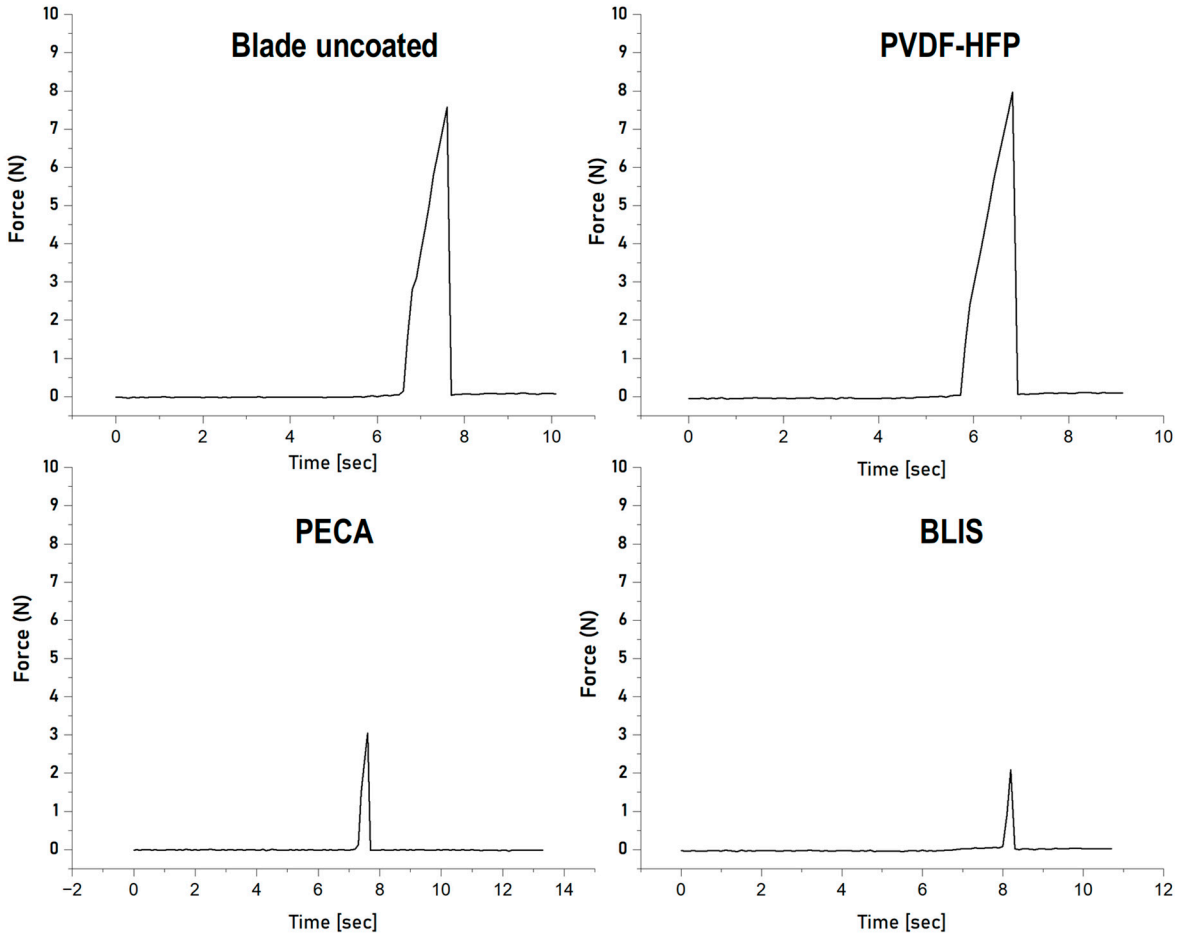


Figure S6. Graphs representing the force applied vs time for the blade uncoated, PVDF-HFP fibers, PECA fibers and BLIS.