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CIGELE

Hydrophobic and anti-ice properties of homogeneous and heterogeneous nanoparticle coatings on Al 6061 substrates

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Outline

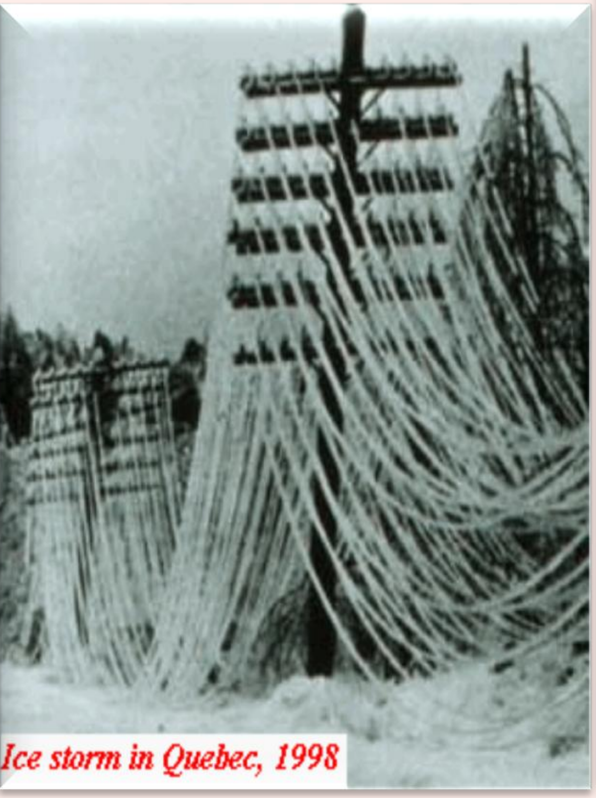
- ***Introduction***
- ***Background***
- ***Objectives***
- ***Methodology***
- ***Results and Discussion***
- ***Summary***

Introduction

- **Icing on structures in cold climate countries**

Ice storm in USA, 1998

Introduction



Ice storm in Quebec, 1998

Introduction

A. De-icing methods

- ✓Mechanical de-icing
- ✓Chemical de-icing
- ✓Thermal de-icing

Advantage

- ➢ Widely used and applicable compare to anti-icing ones

Main disadvantage

- ➢ Using after ice build-up on structures

Disadvantages

- ➢ Frequency of application,
- ➢ Cost issues
- ➢ Significant negative environmental impacts (toxicity)

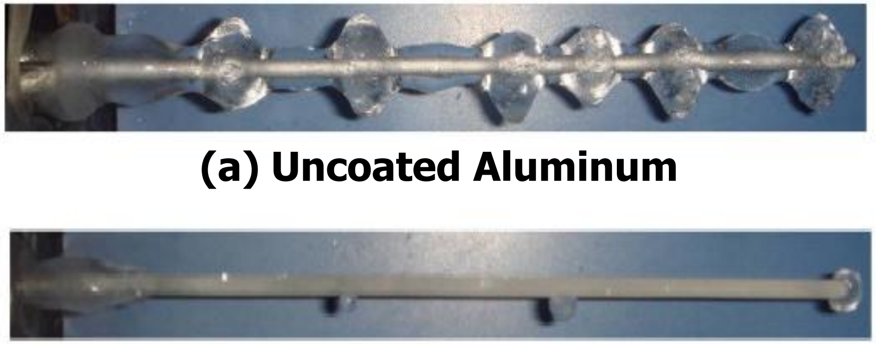
Introduction

B. Anti-icing methods

✓ *Anti-icing or ice-phobic coatings*

Main advantage

➢ *Prevention ice accumulation on a surface in advance*



(a) Uncoated Aluminum

(b) Coated Aluminum

Disadvantage

➢ *Limited used and applicable compare to de-icing methods*

Advantages

➢ *Environmentally friendly compared to de-icing methods,*
➢ *Long service-life (durability),*
➢ *Significantly reduction of ice adhesion strength,*
➢ *Good cost effectiveness*

Background

❖ *Anti-icing or ice-phobic coatings*

General approach and surface treatments for icephobicity:

(i) Self-assembled monolayers with $-CH_3$ or $-CF_3$ groups oriented outward to the ice surface,

(ii) Introducing micro-/nano scale roughness on substrate surface to increase air pockets density follow by applying low surface energy materials,

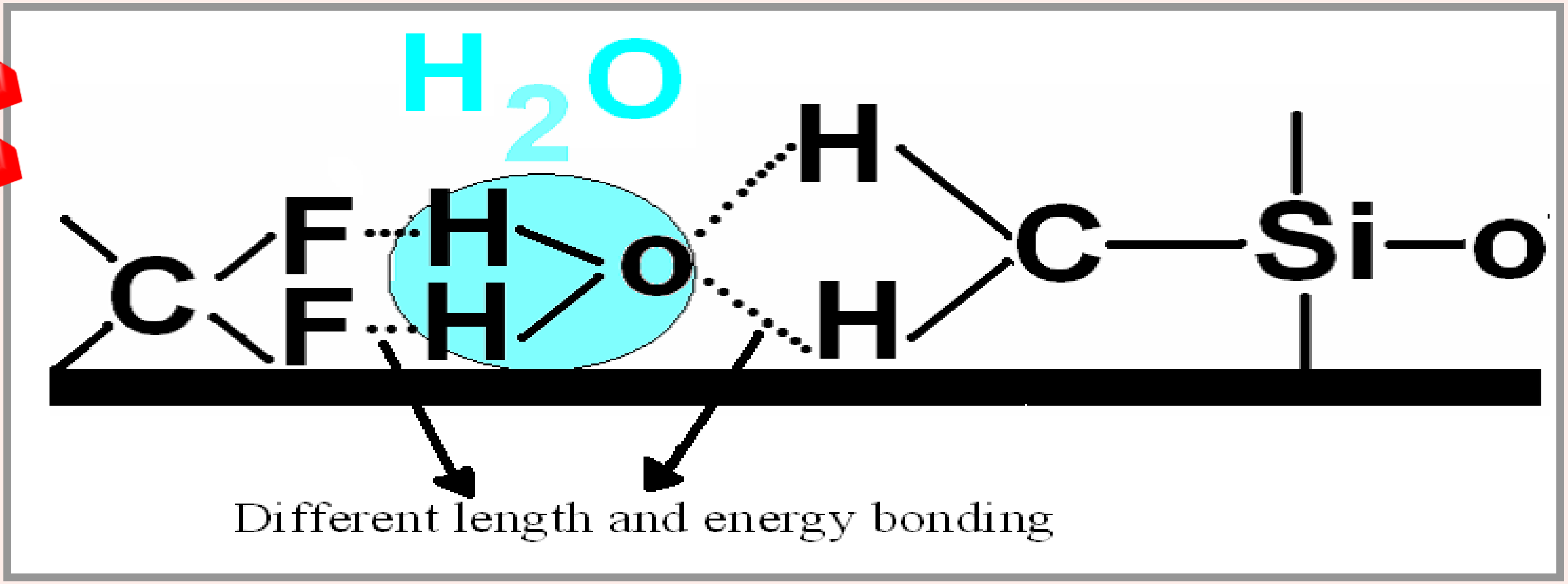
(iii) Coatings with heterogeneous chemical composition of at least two hydrophobic components to disturb the structure of the liquid-like layer.

Background

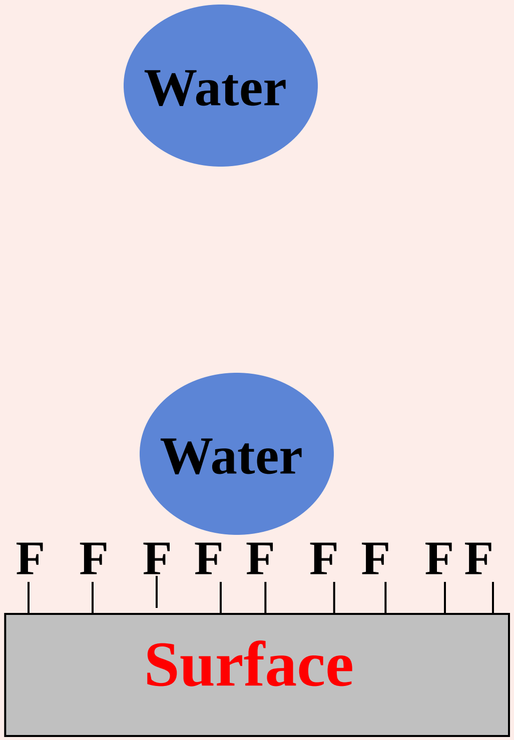
➢ ***Heterogeneous coating***

1) ***Polyperfluoroalkyl(meth)acrylate combined with hydrophobic silicon dioxide (A),***
2) ***Organopolysiloxane modified with a lithium compound (B).***

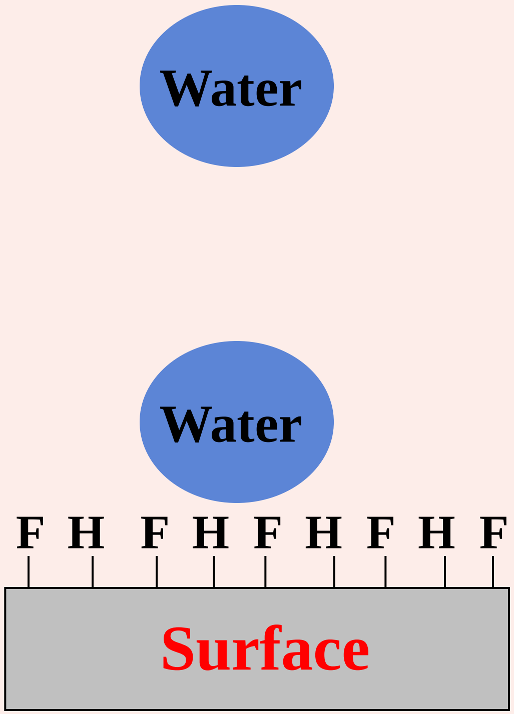
….. compared to PTFE (homogeneous coating)



Heterogeneous *coating*



Homogeneous coating



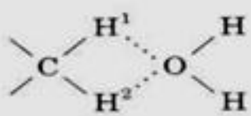
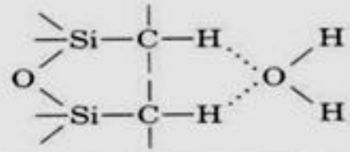
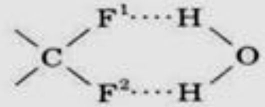
Heterogeneous coating

Background

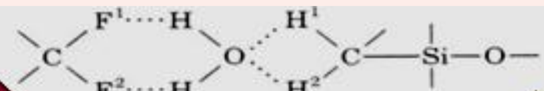
➢ ***Theoretical investigation of heterogeneousity effect***

Homogeneous coating

H. Murase et al.

Interaction Forms			
Bond length (nm) (OH, FH)	0.252	0.329	0.187
Interaction energies (kJ/mol) E_1^1	−14.95	−15.64	−50.89
E_1^2	−5.70	−12.30	−48.51
E_2	−4.07	−4.64	−0.40
E_3	−0.81	+1.75	−39.89
E_4	−1.40	+1.79	−35.81

E_1: $O_{H_2O} - H_{HC,DMS}F_{FHC} - H_{H_2O}$.
E_2: O_{H_2O} − $mol_{HC,DMS}$.
E_3, E_4: H_{H_2O} − $mol_{HC,DMS,FHC}$.

Interaction Forms			
Bond length (nm)	(F—H) 0.307		(O—H) 0.267
Interaction energies (kJ/mol) E_1^1	−10.28		−9.60
E_1^2	−13.62		−7.58
E_2	−0.94		+2.41
E_3	−0.32		−5.00
E_4	−2.58		−2.07

E_1: $F_{FHC} - H_{H_2O}$, $O_{H_2O} - H_{DMS}$.
E_2: O_{H_2O} − mol_{DMS}.
E_3, E_4: H_{H_2O} − mol_{FHC}.

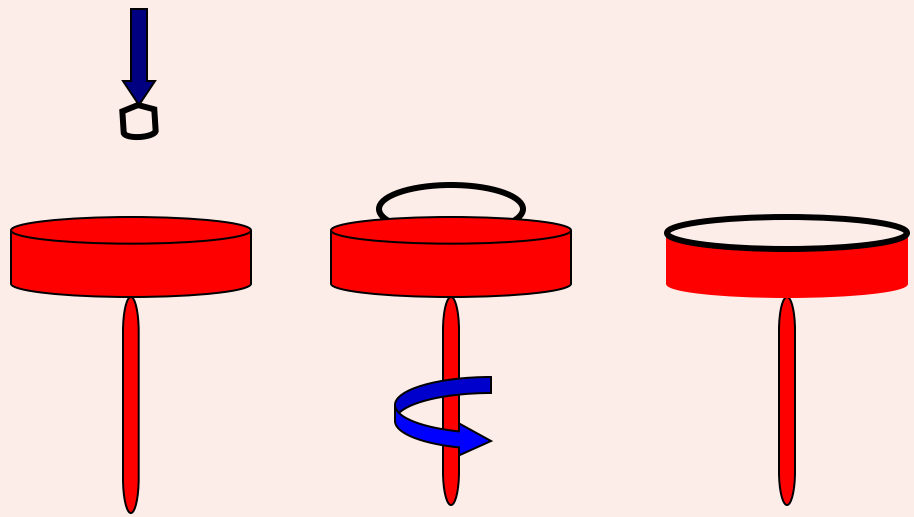
Heterogeneous coating

Objectives

➢ ***Preparation and characterization of HC nanoparticle coatings in terms of hydrophobicity and icephobicity,***

Spin coating

Laurel *(WS-400B-6NPP)*-CIGELE

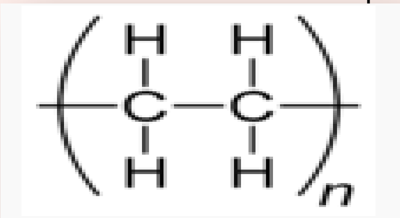
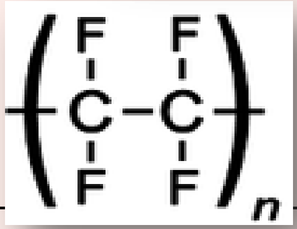


Stage 1 **Stage 2** **Stage 3**

spinning rate {
V = 500 rpm
T = 15 s

Methodology

❑ ***Preparation of heterogeneous nanoparticle coating***

Material	Structure
Polyethylene (PE)	
Polytetrafluoroetylene (PTFE)	

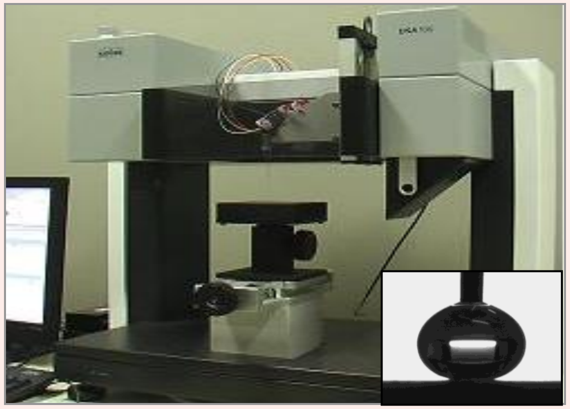
Methodology

➢ ***Examples of "heterogeneous coating" preparation***

Material	Quantity	Solvent	Method	Company	Abbreviate
PE	1 gr	50 ml Toluene (at 110º cc)	Spin coating	Good-fellow	PE-spin
PTFE	1 gr	50 ml Toluene	Spin coating	Sigma-Aldrich	PTFE-spin
PE, PTFE	1 gr, 1 gr	50 ml, 50 ml Toluene	Spin coating	Good-fellow, Sigma-Aldrich	PE-PTFE
PE, PTFE	1 gr, 1 gr	100 ml Toluene	Spin coating	Good-fellow, Sigma-Aldrich	PE+PTFE

Characterization

Sample Wetting Properties



Kruss DSA100 Water Contact Angle Goniometer (CIGELE)

Sample Anti-ice Performance

Centrifuge adhesion test machine (CIGELE)

- *X-ray photoelectron spectroscopy (XPS)*
- *Scanning electron microscopy and energy-dispersive x-ray spectroscopy (SEM)/(EDS)*
- *Atomic force microscopy (AFM)*

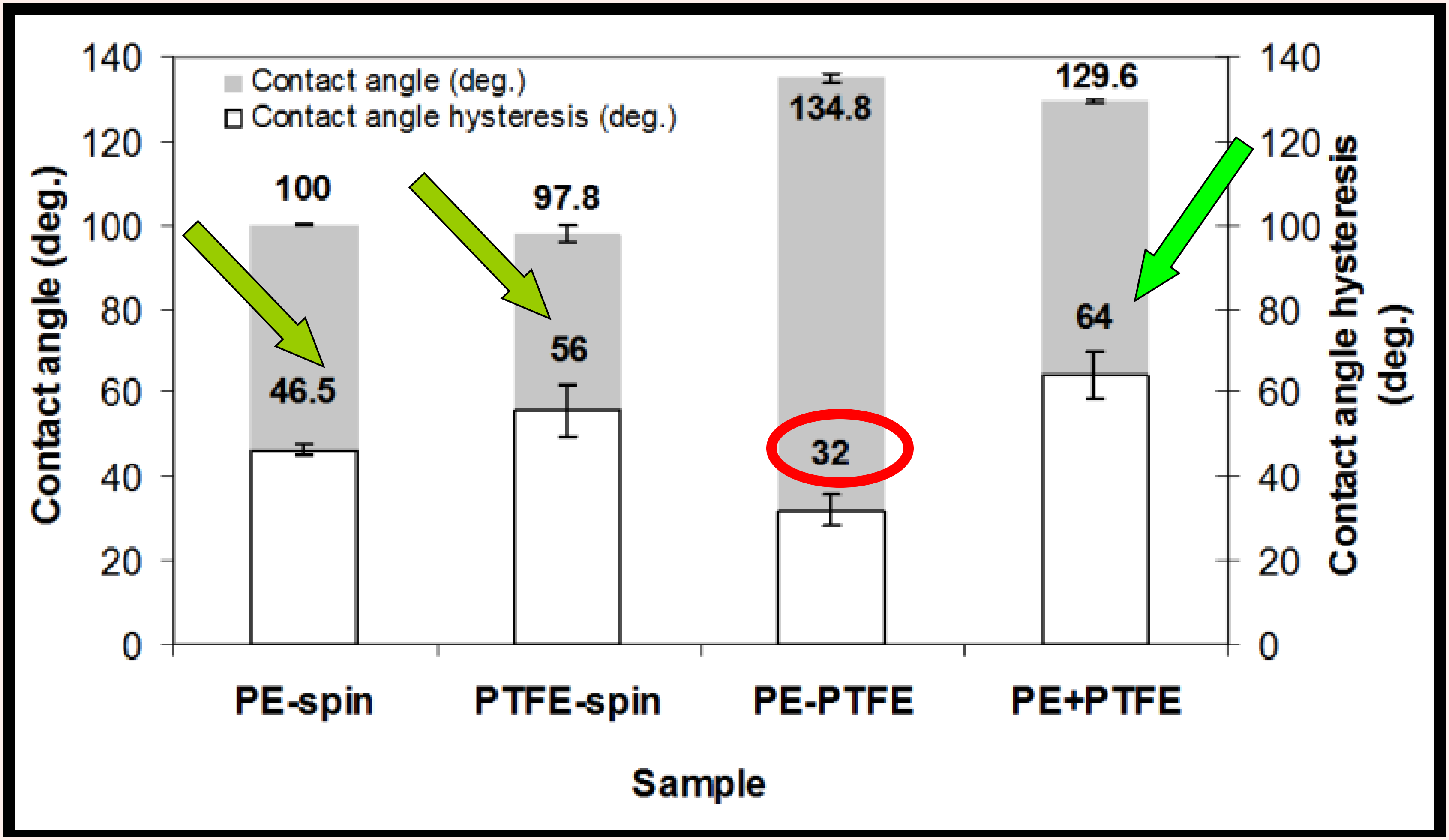
Results: *HC nanoparticle coatings*

- **CA values of homogeneous and HCs made of PE and PTFE**

Coating	PE	PTFE (200nm)	PE-PTFE	PE+PTFE
CA values	100°± 0.36	97.8° ± 1.83	134.8° ± 1	129.6° ± 0.6

- **This table presents the 'heterogeneity *effect*', however there is problem of roughness effect created by PTFE nanocomposite.**
- **HC coating of PE-PTFE was prepared to investigate separately the hydrocarbon and fluorocarbon effect.**
- **Mixture of PE and PTFE, named as PE+PTFE coating, was also prepared to study the effect of roughness.**

Results: *HC nanoparticle coatings*



Surface characterization: *AFM results*

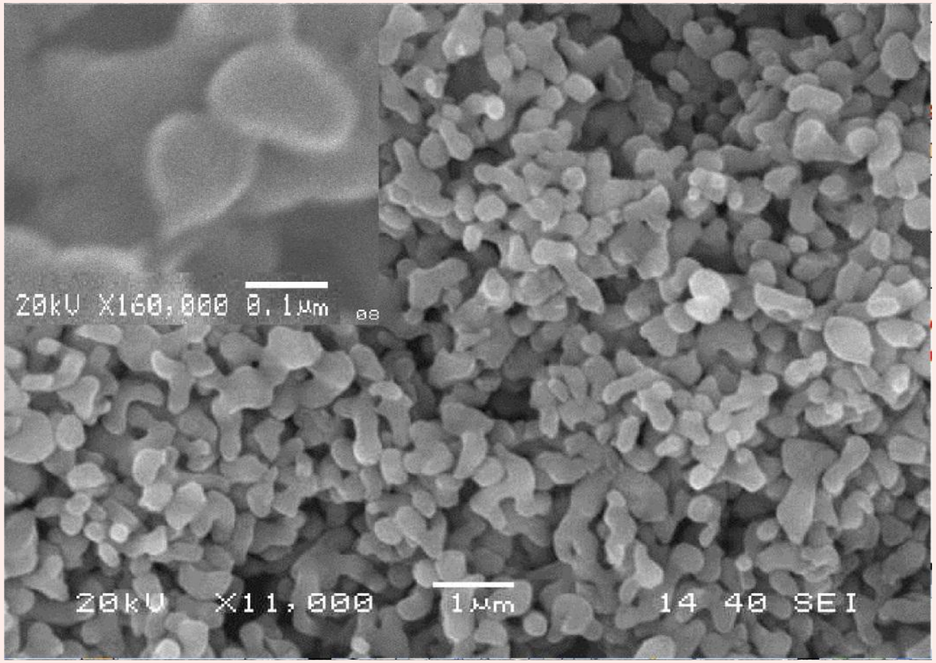
•The R_{rms} (nm) of homogeneous and HC samples.

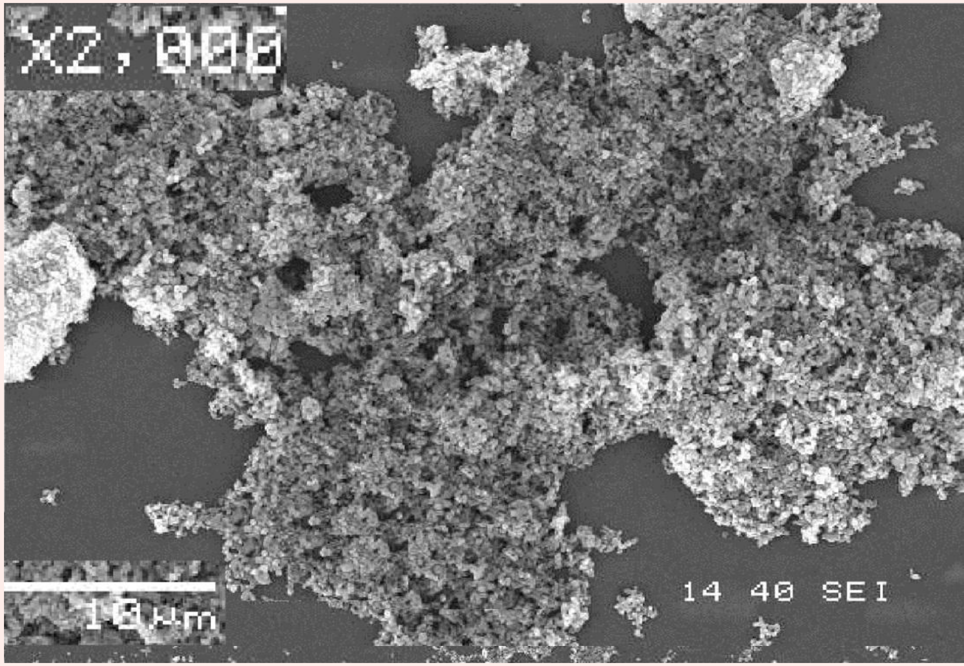
Sample	Root mean square (nm)
PTFE-spin	165.5 ± 68.58
PE+PTFE	**284.79 ± 173.14**
PE-PTFE	**239.85 ± 145**

- The R_{rms} values of the PE+PTFE and PE-PTFE coatings are close together, however…
- The CA and CAH values of PE+PTFE sample were smaller and bigger, respectively, than what observed for PE-PTFE sample.

Surface characterization: *SEM results*

❑ **SEM images of PE-PTFE sample, at ×30, ×300, ×2000, ×11000 and ×160000 magnifications.**





➢ **SEM images of PE-PTFE demonstrates the propagated islands of nanoparticle in several areas and spots.**

Ice adhesion results

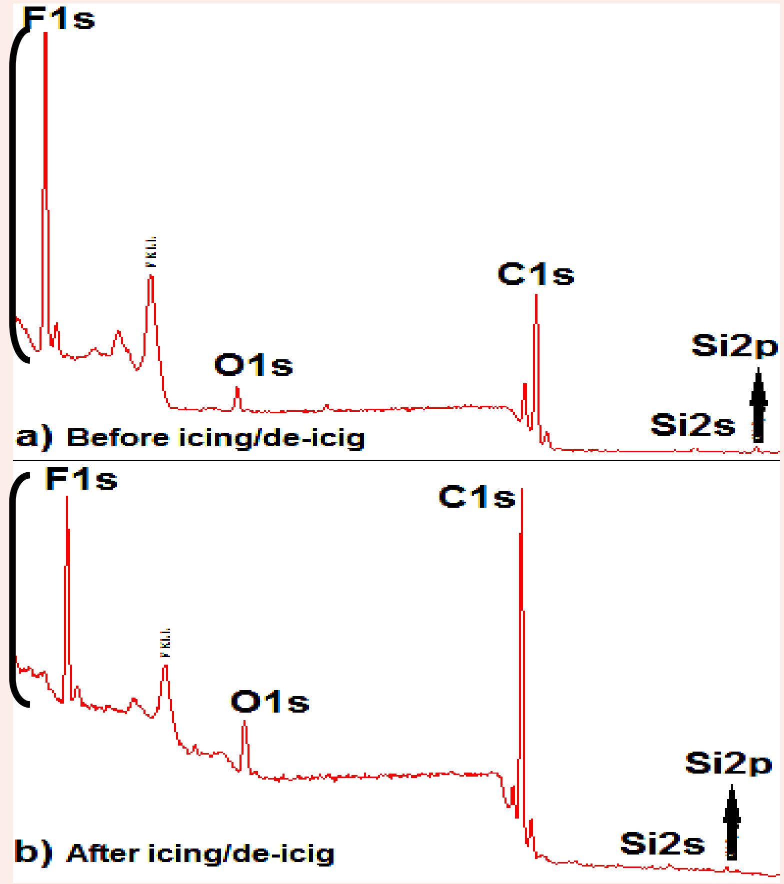
❑ **Ice adhesion strength and *ARF* values of homo/heterogeneous nanoparticle coatings**

Sample	Ice adhesion strength (kPa)	*ARF*
Polished Al	251.5 ± 27	1
PE-spin	220.8 ± 19.3	1.1
PE-PTFE	**190.7 ± 34**	**1.32**

➢ ***The ARF* values of HC samples show at least ~1.3 times lower ice adhesion strength than those obtained on polished Al sample.**

Surface characterization: *XPS results*

- **XPS results of PE-PTFE sample showed partial remove of PTFE nanoparticles after icing/de-icing cycles.**



XPS results of PE-PTFE sample before and after icing/de-icing

Element	C 1s %	F 1s %	O 1s %	Si 2p %
Before icing/de-icing	68.30	26.41	2.86	2.18
After 2 times icing/de-icing	83.37	10.10	5.26	1.28

Conclusions

- The wetting behavior, morphology and ice-releasing performance of nanoparticle-based homogeneous and HC coatings on Al surfaces confirmed the “effect of heterogeneity” on sample hydrophobic and ice-phobic properties;

- Meanwhile, CA and CAH measurements approved again the effect of heterogeneity on such coated surfaces;

- The AFM analysis also confirmed different sample morphology due to heterogeneity effect on Al substrates;

- Anti-ice performance of prepared HC nanoparticle coating was at least ~1.3 times lower than polished Al sample while for homogeneous PE-spin coating the ARF was ~ 1.1 times lower than polished Al sample;

- The XPS analysis showed partial remove of PTFE nanoparticles after several icing/de-icing cycles;

Thank you for your attention!