



Engineered Materials Workshop

Part C: Adhesion Prevention and Durability

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Technologies

Copoly(Imide Alkyl Ether)

Epoxy Alkyl Ether Particulate Composites

Surface Topography and Silanation

Tech Transfer Workshop

May 22, 2014



Outline

- Surface Modifying Agents-Oxetane Derivatives
 - Case Study 1-Abrasive Particulates (Lunar Dust)
 - Case Study 2-Environmental Contaminants (Insect Residues)
 - Durability Assessment
 - Minor Studies-Biofouling, Drag Reduction/Fluid Flow Modification
- Silanated, Topographically Modified Surfaces
 - Case Study 3-Insects and Ice Adhesion Mitigation



Surface vs Bulk Modification

Scenario: You want a non-stick surface with excellent mechanical properties. How do you get there?

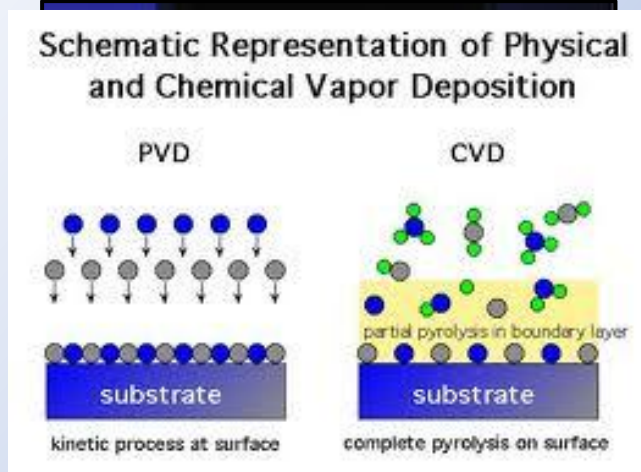
Property	Polyimide	Polycarbonate	Epoxy	ABS	Teflon
Tensile Modulus, MPa	2,500	2,210	3,450	1,720	27
CTE, x PPM °C ⁻¹	20	70	14	90	135
Typical Contact Angle	90°	80°	75°	80°	105-110°



Active vs Passive Modification

Active Surface Modification Techniques

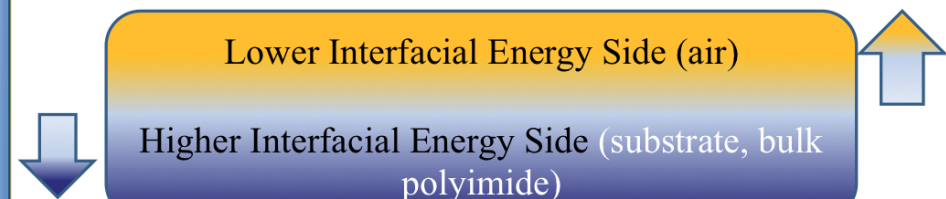
- Coatings
- Plasma/Corona Discharge
- Physical/Chemical Vapor Deposition



Passive Modification Techniques

- Coatings
- Surface Exfoliation/Controlled Release
- Surface Migration

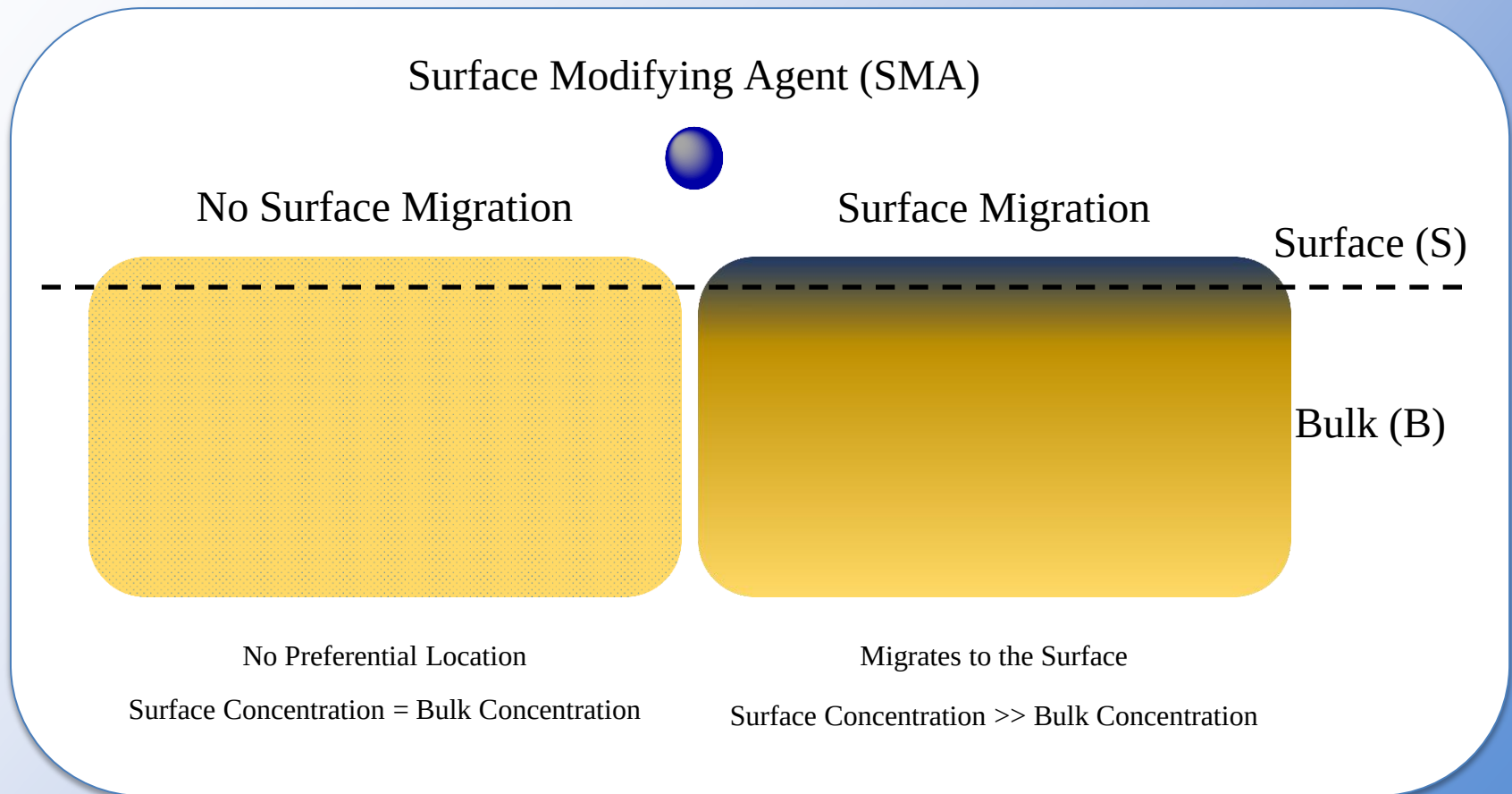
Thermodynamic Response of SMA



Arrows indicate enthalpy-driven migration of **LOW** and **HIGH** surface energy components.



What is Surface Migration?

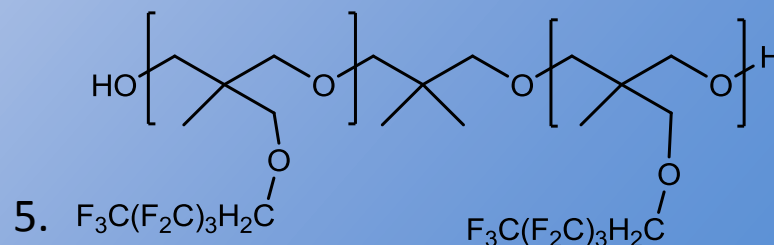
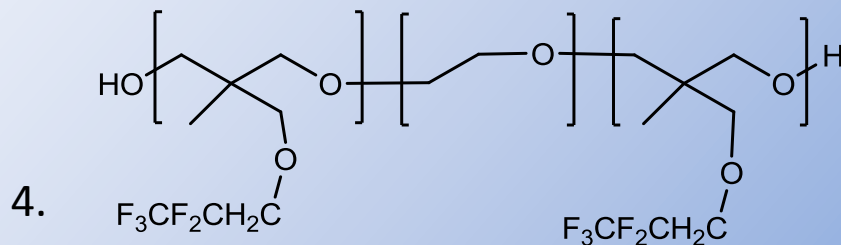
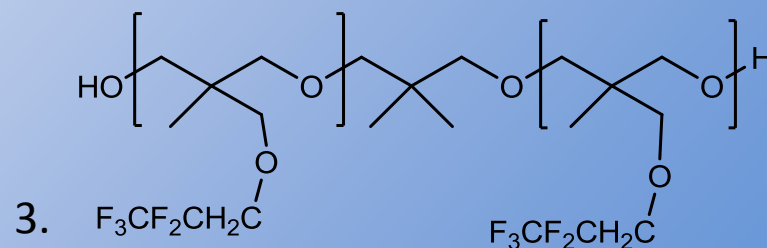
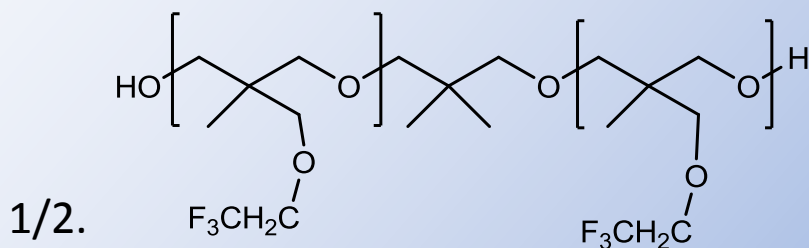




SMA: Oxetane Derivatives

		Side Chain	DP	MW (g/mol)
1	PF-636	CF ₃	6	1150
2	PF-6320	CF ₃	20	3480
3	PF-656	CF ₂ CF ₃	6	1490
4	PF-154N	CF ₂ CF ₃	6	3464
5	PF-7002	(CF ₂) ₃ CF ₃	4	1670

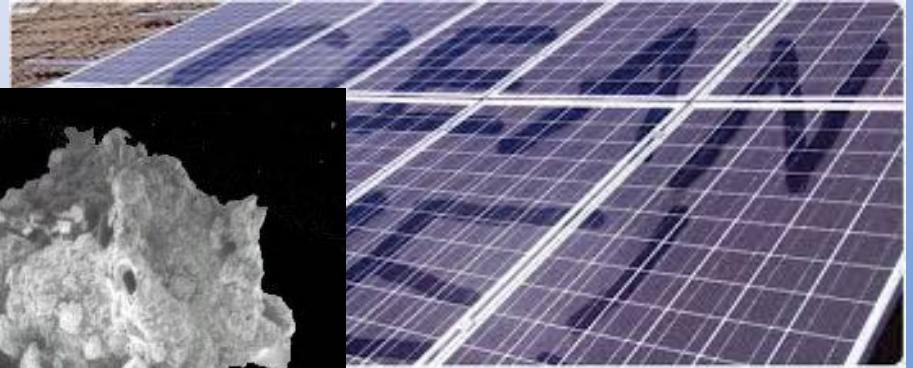
- Alkyl ether oligomers (PolyFox®) obtained from Omnova Solutions Inc.



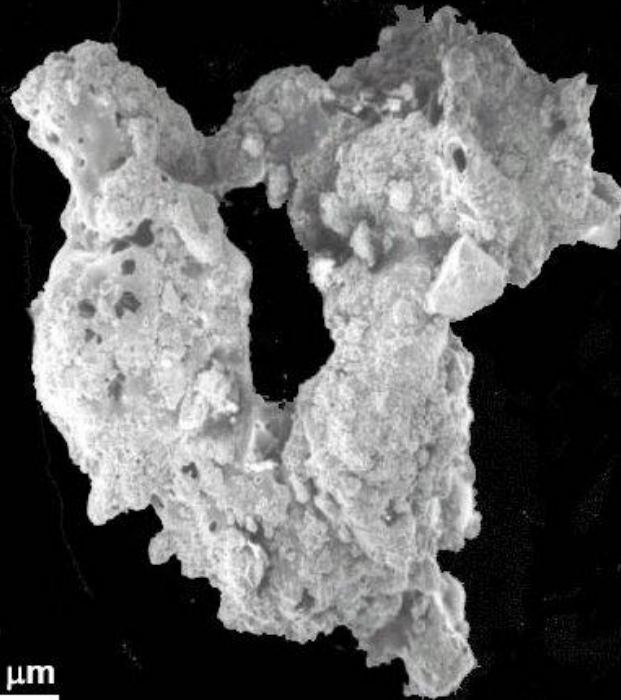


Case Study 1: Particulate Adhesion Mitigation

- What's the problem?

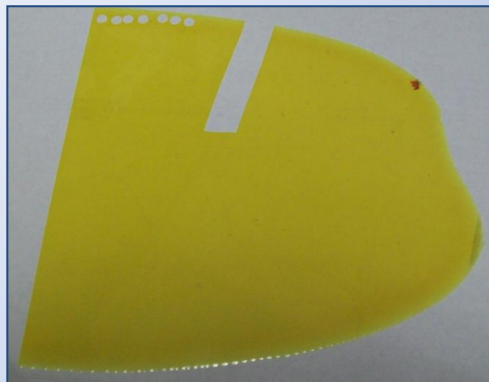
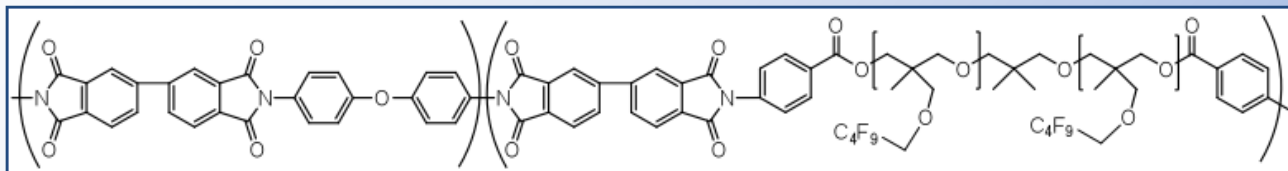


100 μm



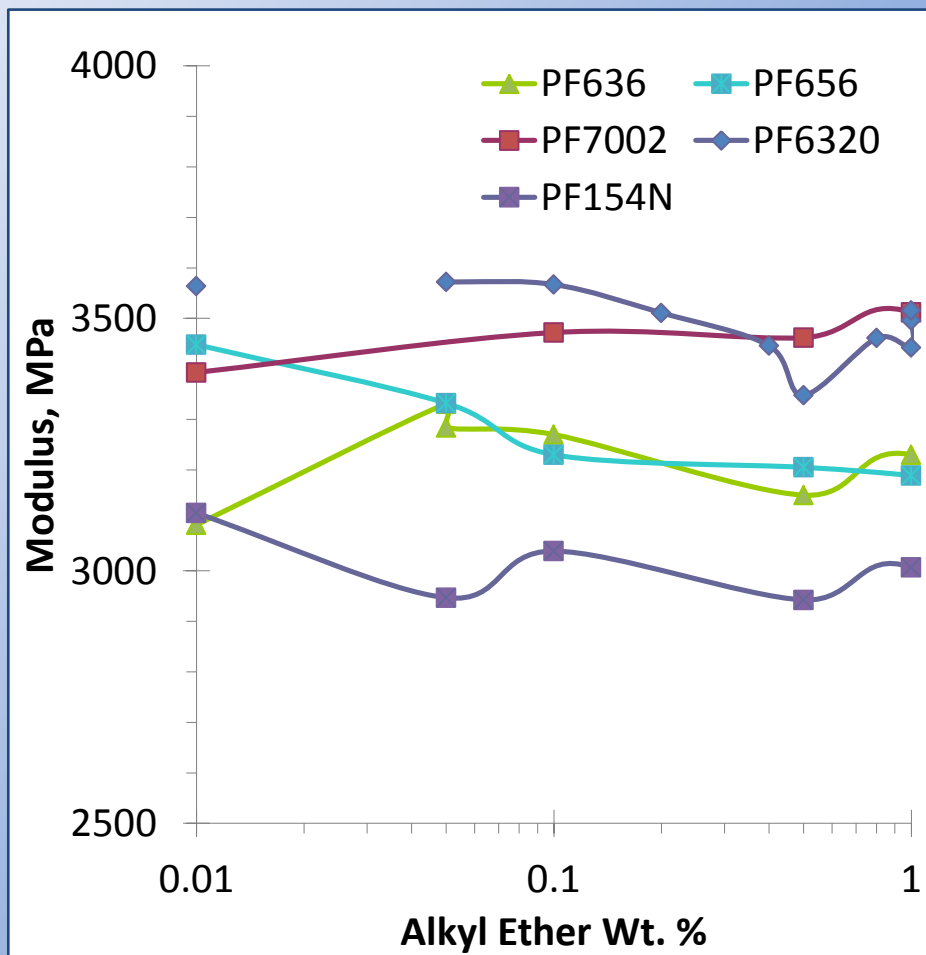
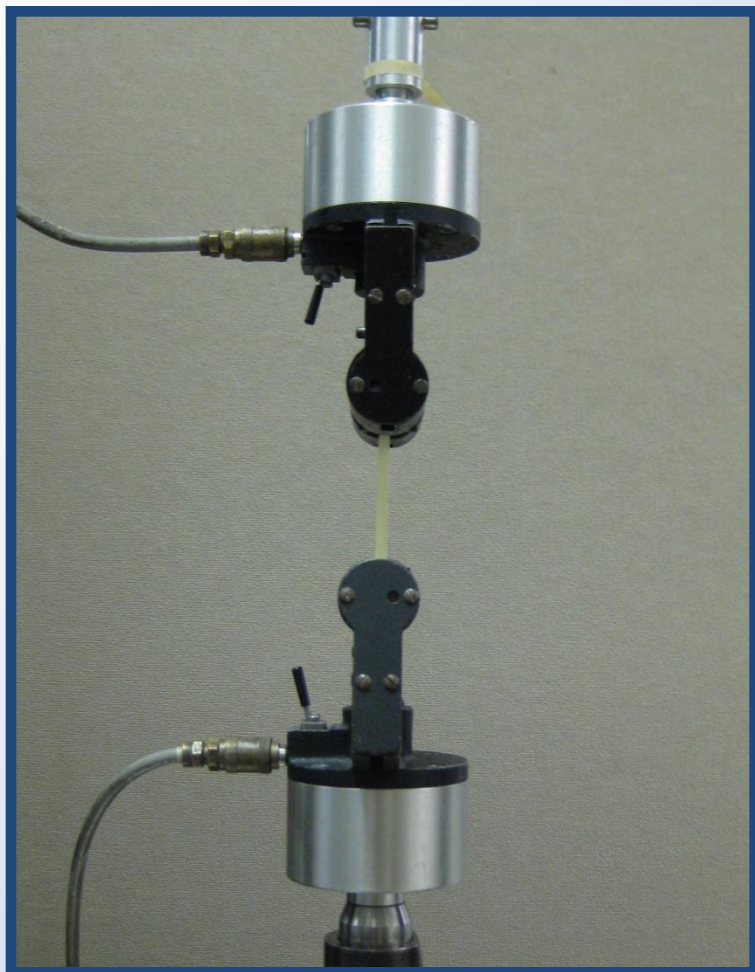


Copoly(imide alkyl ether)s



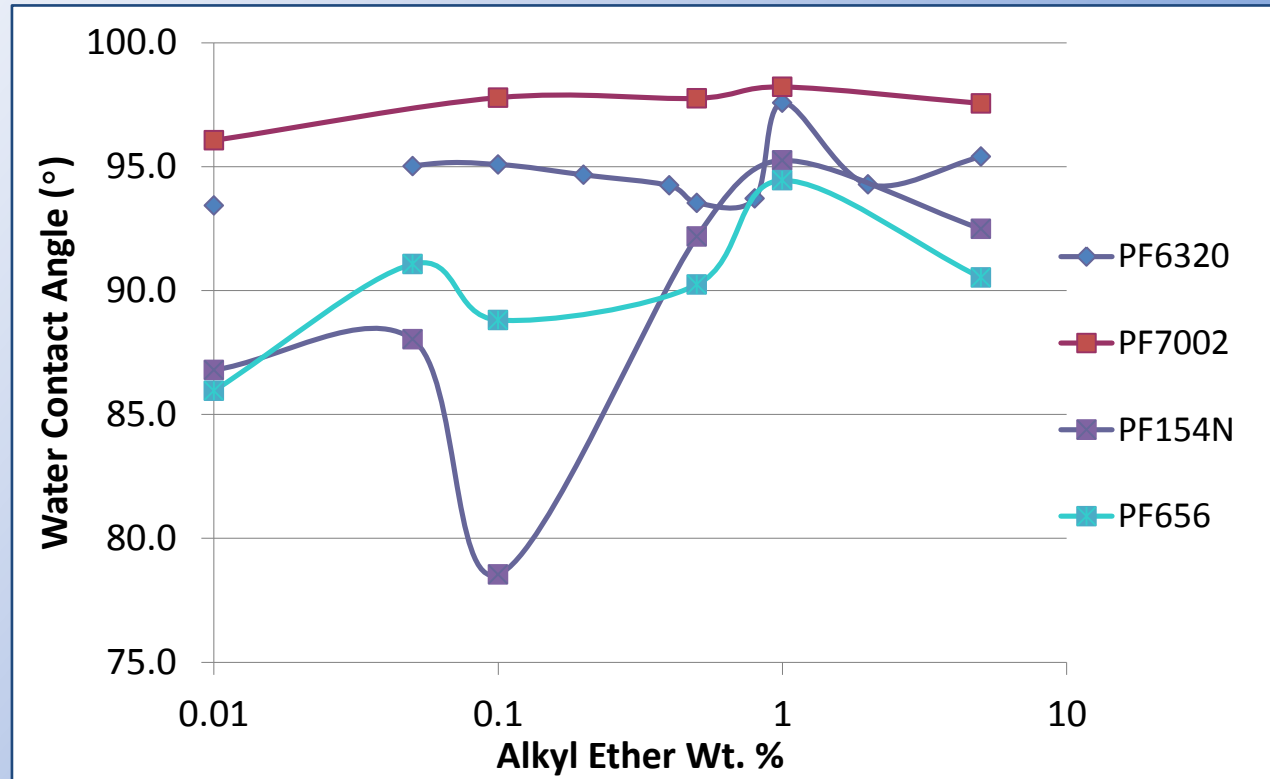
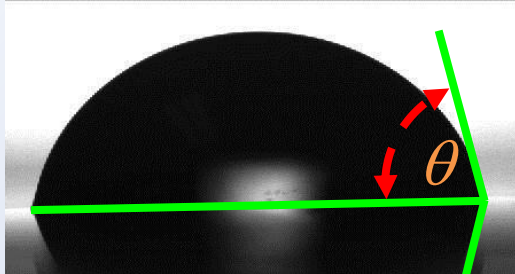
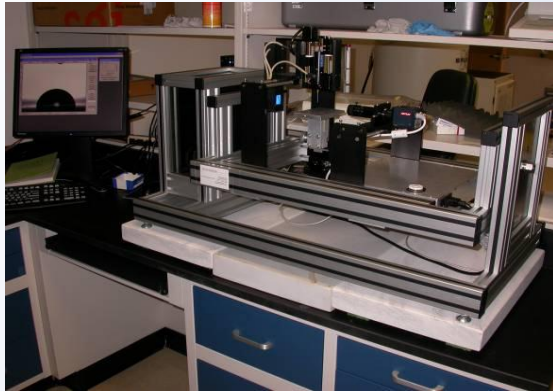


Copoly(imide alkyl ether)s Mechanical Props.



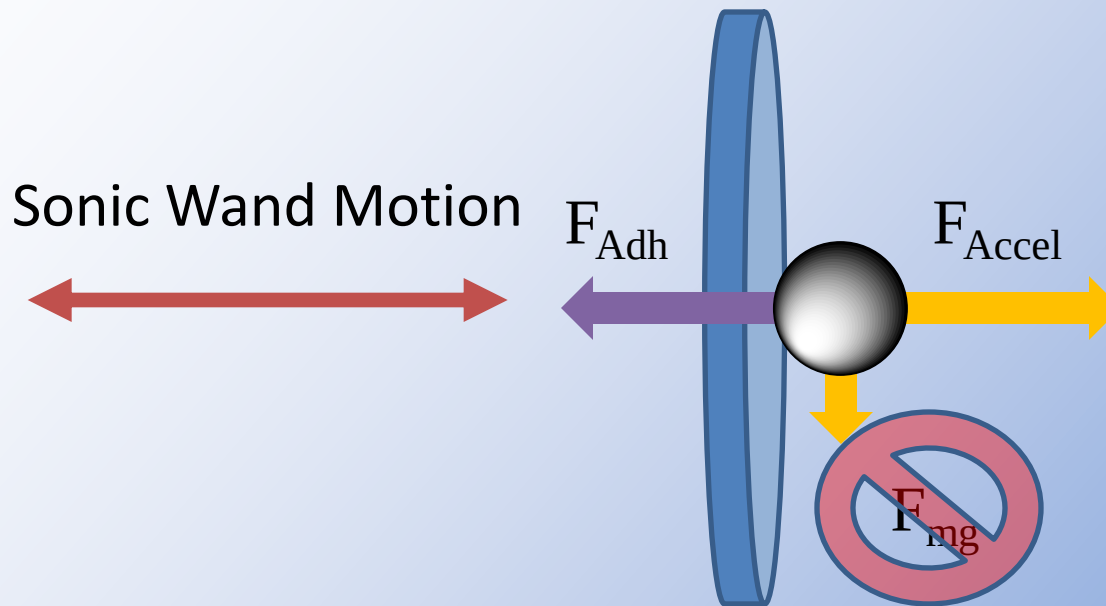


Copoly(imide alkyl ether)s Contact Angle





Adhesion Quantification



Particle will detach when F_{Accel} is $\geq F_{Adh}$

$$F_{Accel} = ma = m * 4\pi^2 * f^2 * A$$

m = particle mass

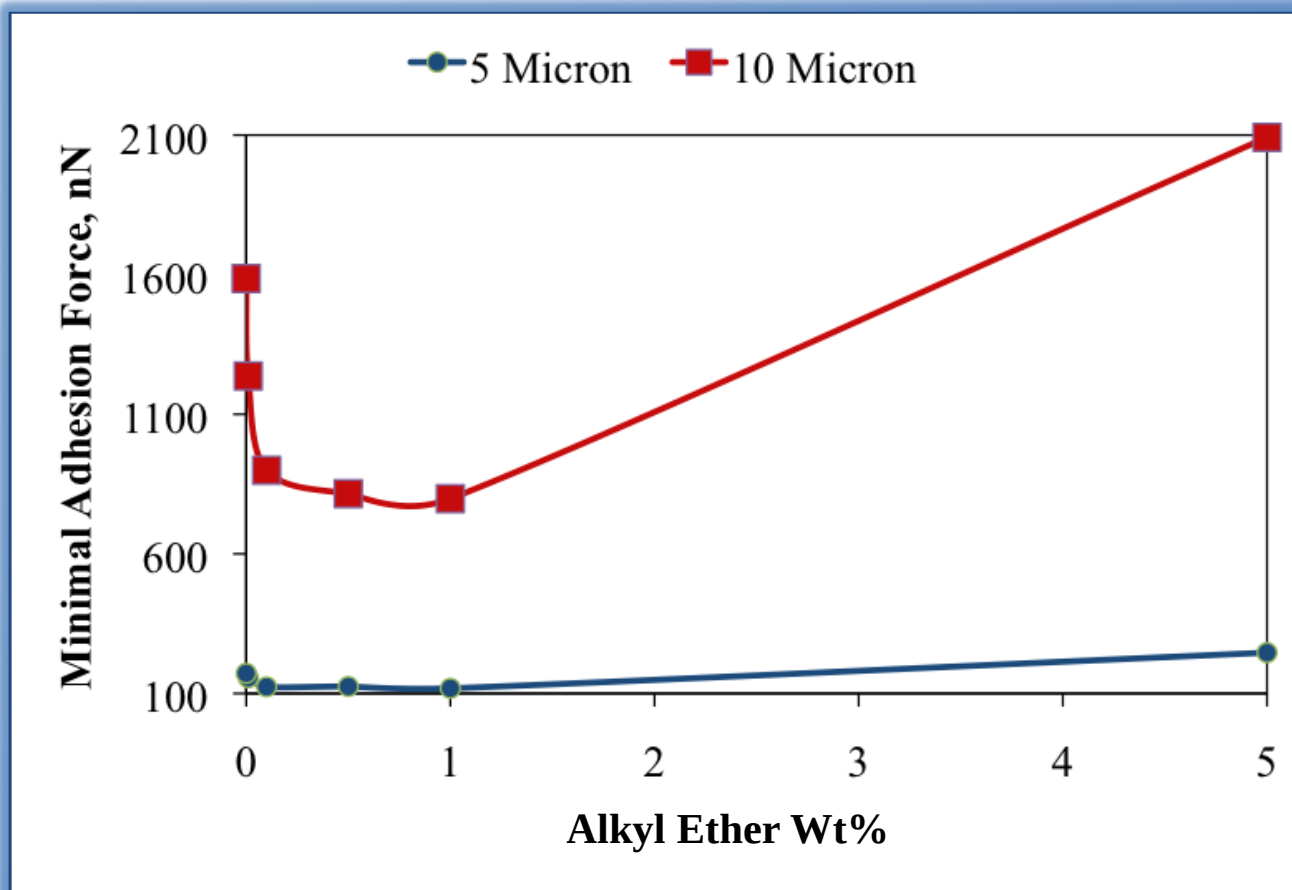
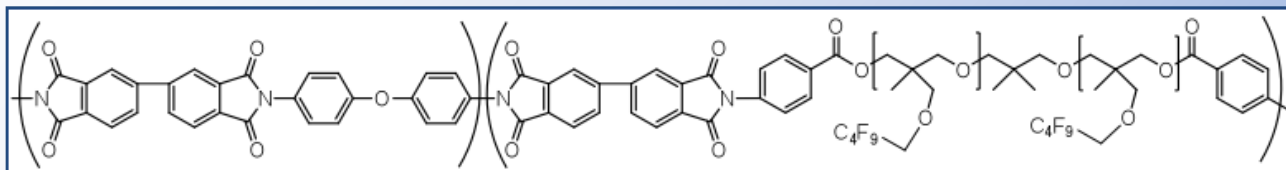
a = acceleration

f = sonic wand frequency

A = sonic wand amplitude

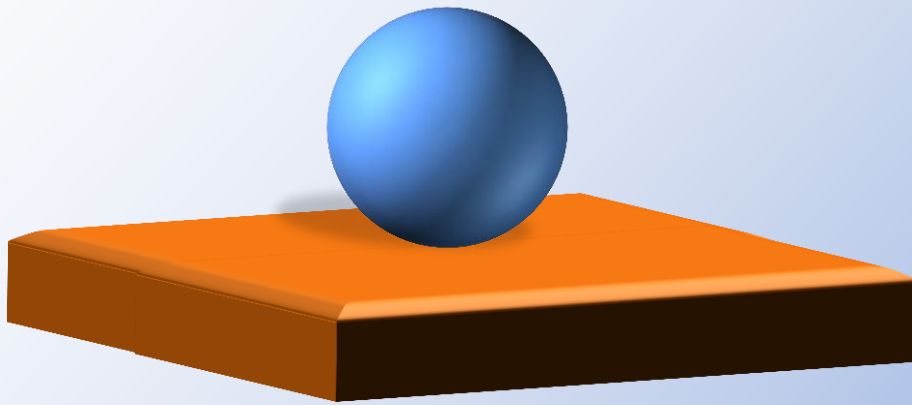


Adhesion Quantification

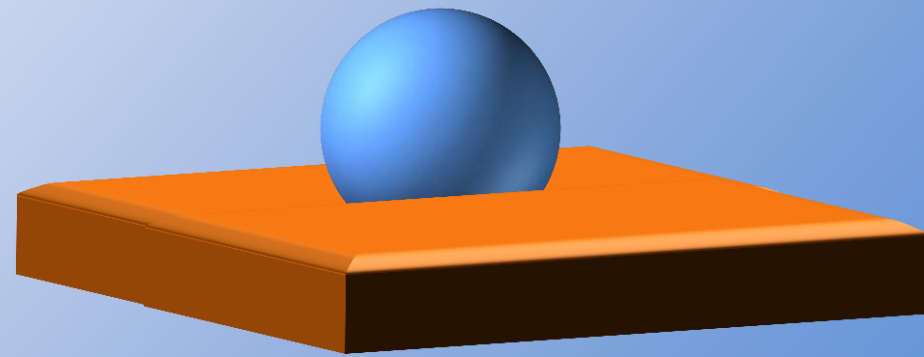




Adhesion Quantification-Surface Softening



Hard Surface



Soft Surface



Case Study 2: Environmental Contamination Mitigation

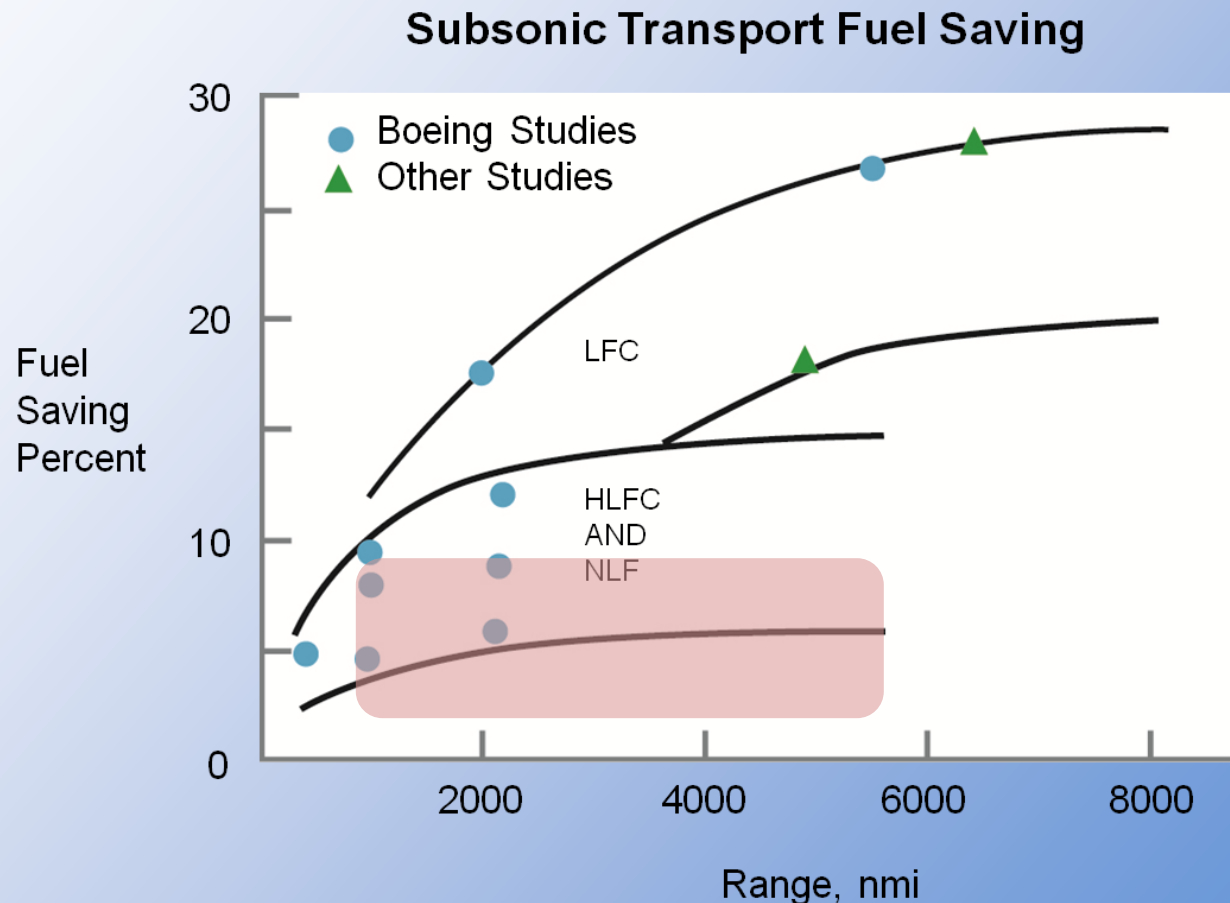
- What's the problem?





Case Study 2: Environmental Contamination Mitigation

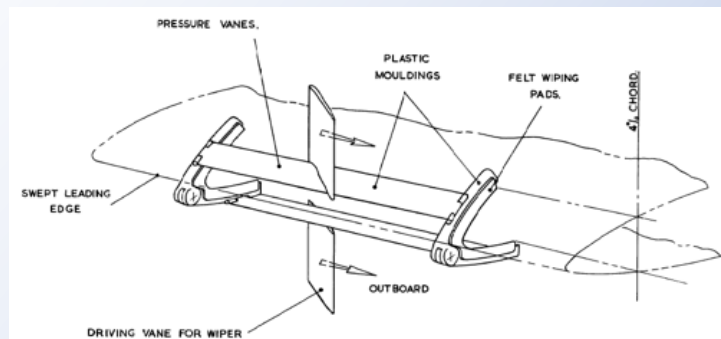
- What's the problem?



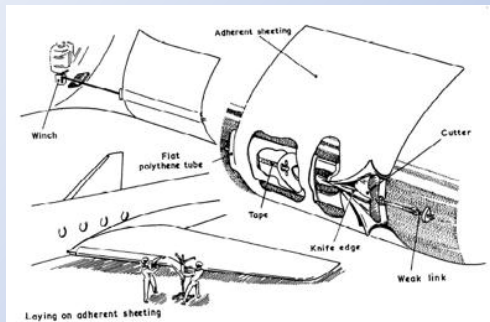


Case Study 2: Environmental Contamination Mitigation

- What solutions exist?



Mechanical Scrapers



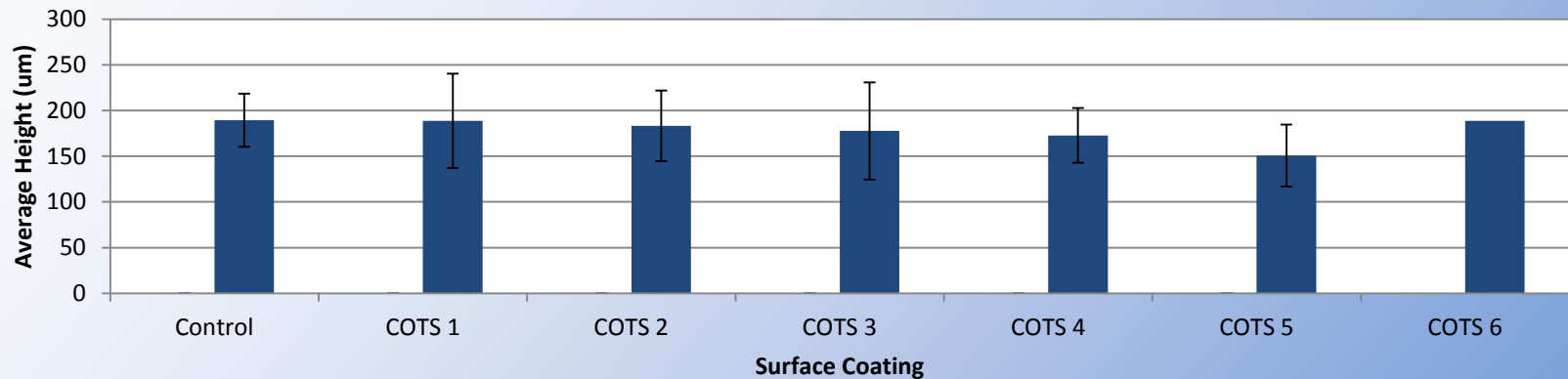
Paper & Other Coverings

- Natural Erosion
- Deflectors (i.e. Krueger flap/shield)
- Elastic Surfaces
- Coatings
- Soluble Films and Fluid Covers

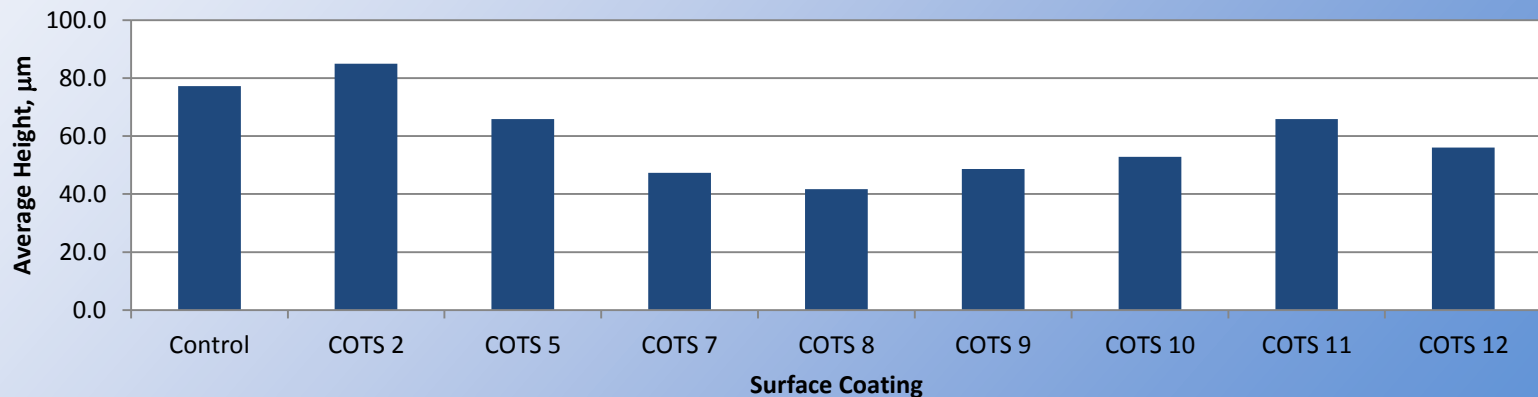


Case Study 2: Environmental Contamination Mitigation

- What coatings exist? ... lots



Cricket Impacts

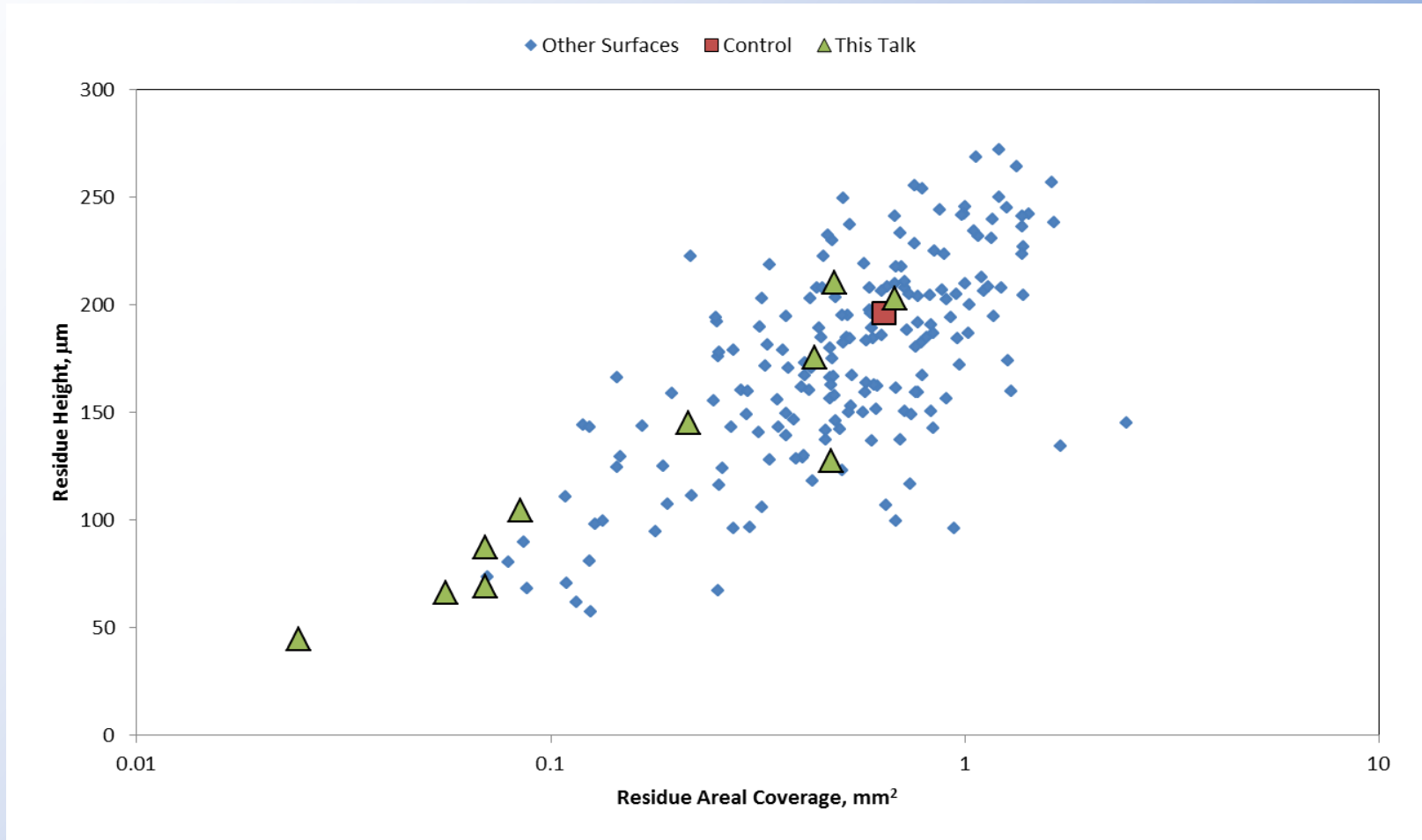


Fruit Fly Impacts



Case Study 2: Environmental Contamination Mitigation

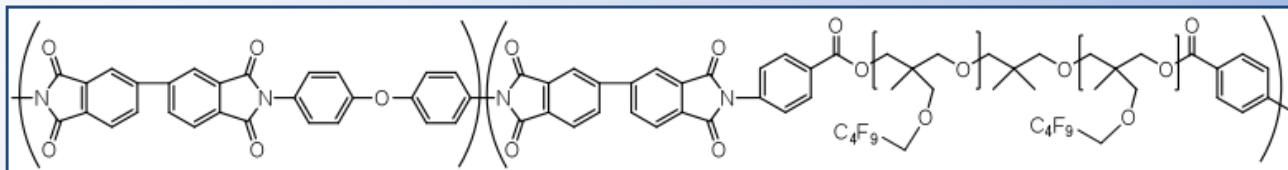
- What coatings have we generated/tested? ... lots



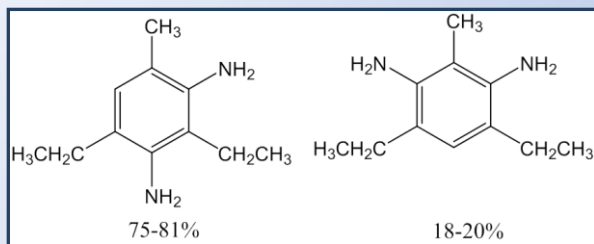


Case Study 2: Environmental Contamination Mitigation

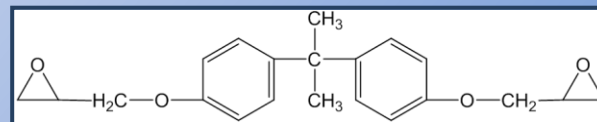
- What has worked? Polymer Particulate Composites



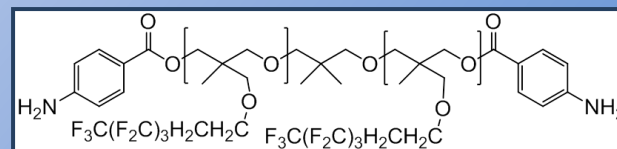
Copoly(imide alkyl ethers)



Ethacure 100



D.E.R. 331 (DGEBA)

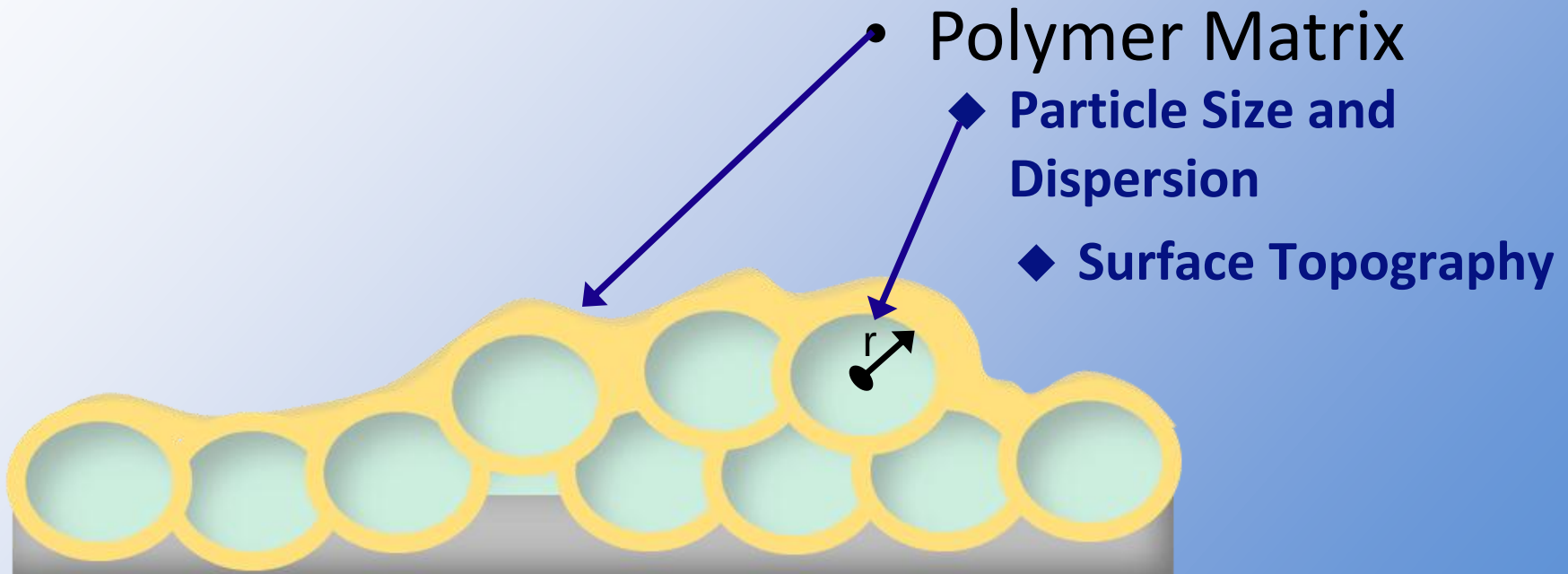
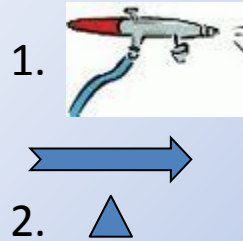


Fluorinated Aliphatic Ether (FAE, ~ 1 wt%)

Epoxy alkyl ethers

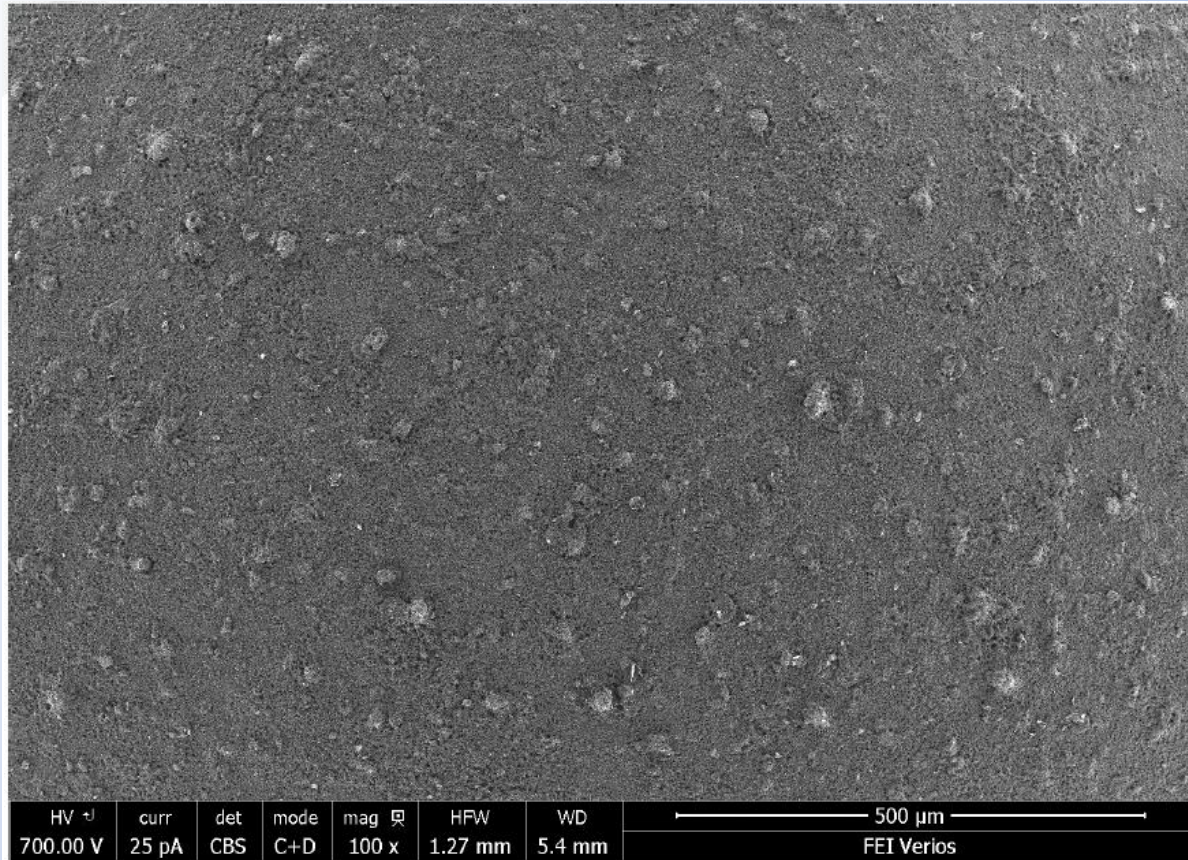


Case Study 2: Environmental Contamination Mitigation





Case Study 2: Environmental Contamination Mitigation



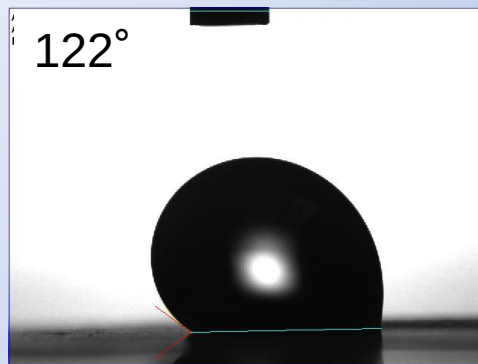
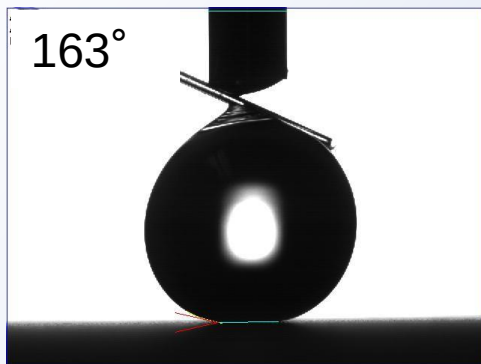
Representative Mixed Filler (MoS_2 and SiO_2) Epoxy Particulate Composite

Images collected on the FEI Verios 460L compliments of FEI.

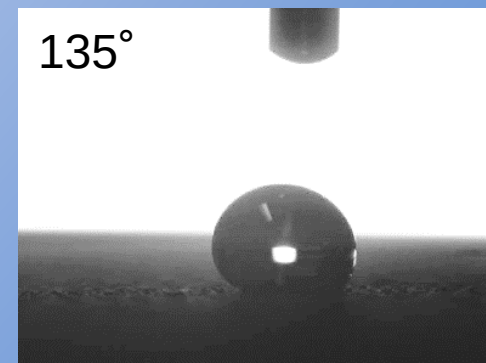
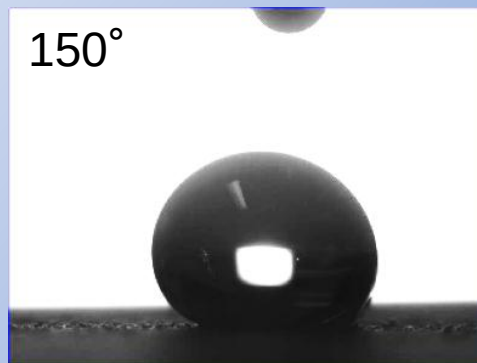
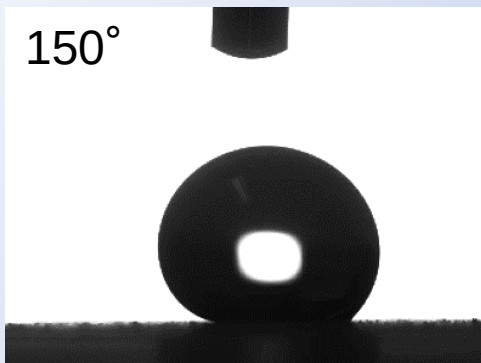


Contact Angle Measurements

Copoly(imide alkyl ether) with 60 wt% fumed SiO_2



Epoxy Alkyl Ether Composite with 6.25 wt% MoS_2 and 18.75 wt% SiO_2



Water

Ethylene Glycol

Methylene Iodide



Operational Environment Testing



Flightless fruit fly
(*drosophila melanogaster*)



Bench-top Wind Tunnel



Case Study 2: Environmental Contamination Mitigation

Video

Copoly(imide alkyl ether) Fruit Fly Impacts



Case Study 2: Environmental Contamination Mitigation

Video

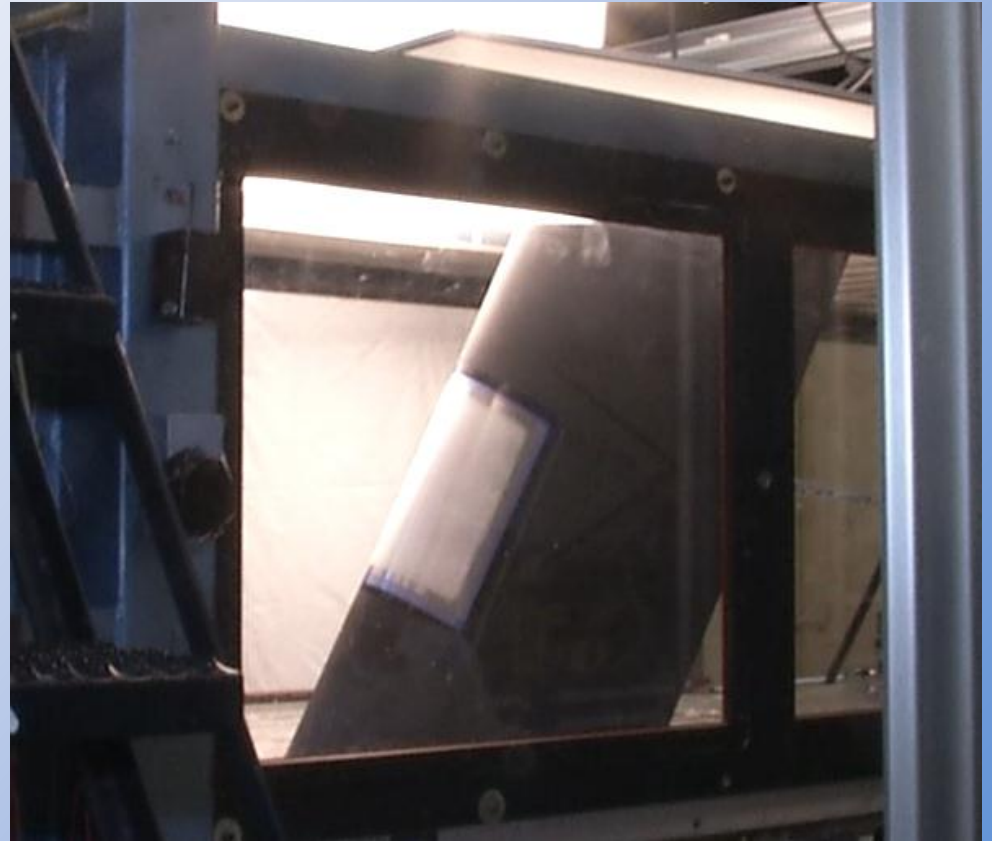
Epoxy Alkyl Ether Composite Fruit Fly Impacts



BART Testing



Flightless fruit fly
(*drosophila*
melanogaster)



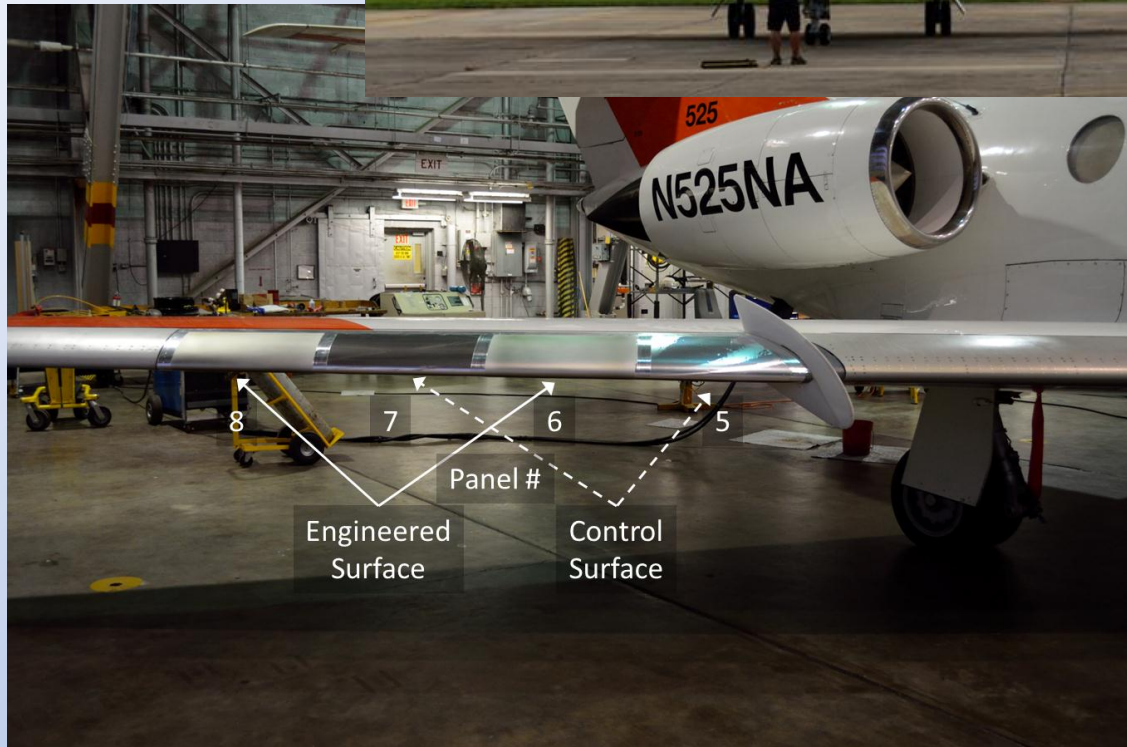
NACA-0015 Airfoil at an AOA of 8°



Flight Testing



Flightless fruit fly
(*drosophila melanogaster*)





Case Study 2: Environmental Contamination Mitigation

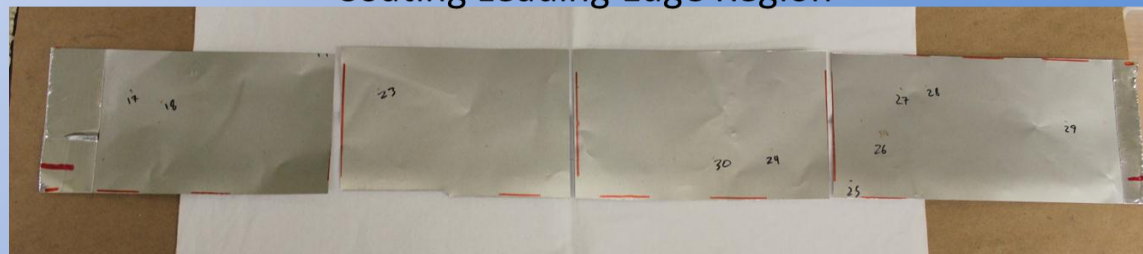
Surface	# of Residues	# of Residues on Control	% Reduction
Epoxy Composite Coating	128	207	38%
Copoly(imide alkyl ether)	383	499	23%



Control Leading Edge Region



Coating Leading Edge Region





Durability Assessment



Multi-Coupon Sample Prep



Accelerated UV-Weathering



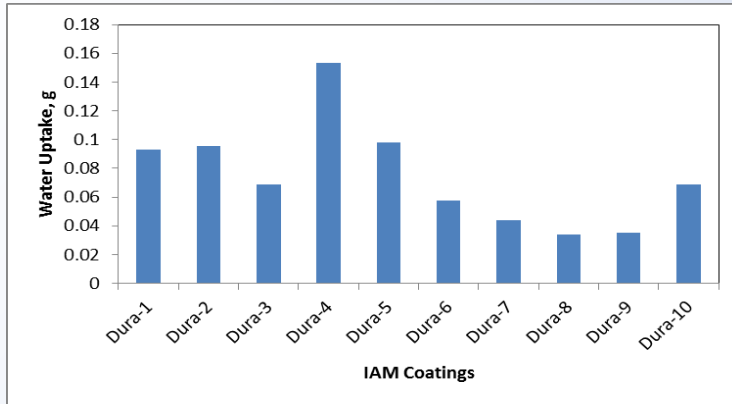
Outdoor Exposure



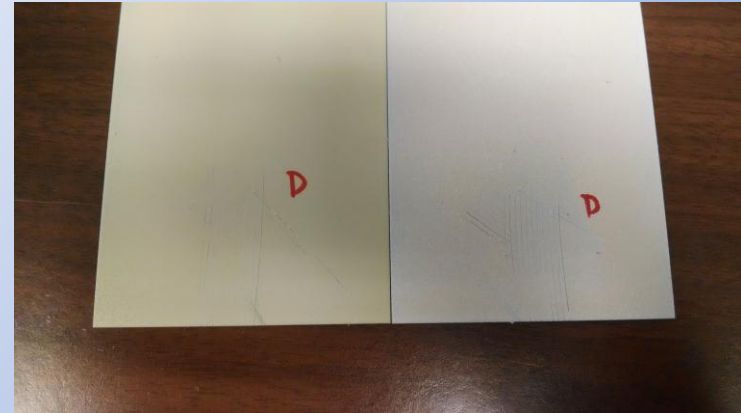
Temp/Humidity
Cycling



Durability Assessment



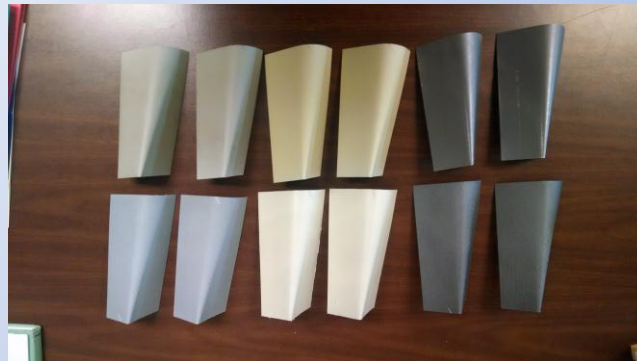
Water Uptake



Dry/Wet Scribe Testing



Flexibility Testing

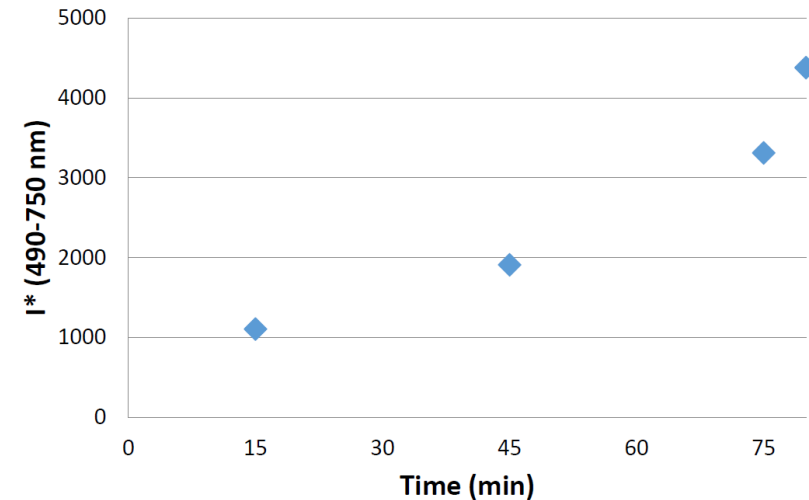


Fruit Fly Impact Testing



Minor Investigations

- Biofouling

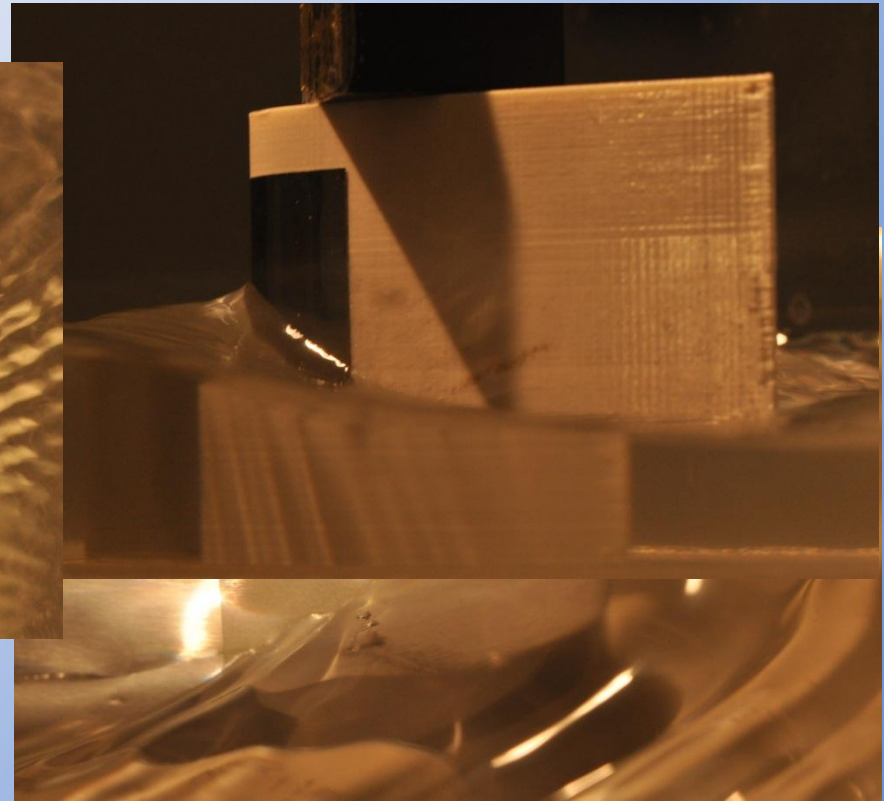
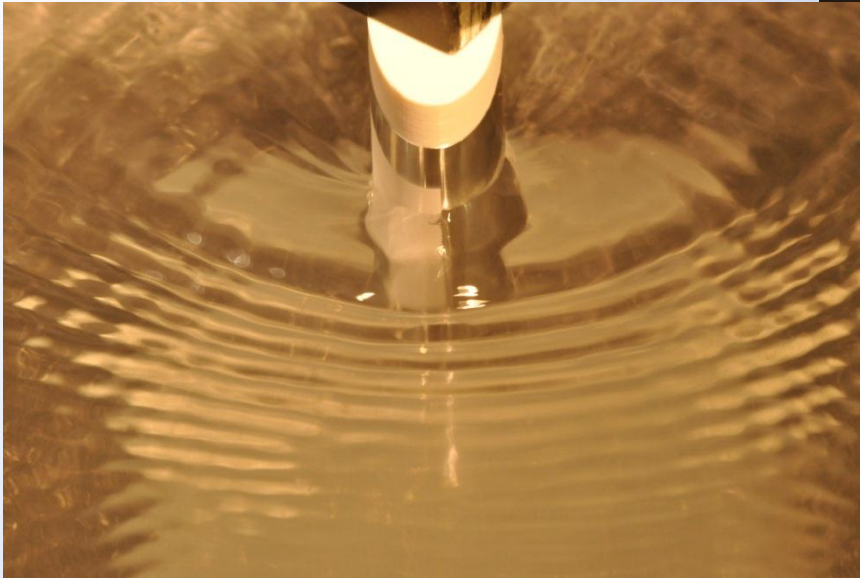


Combination of Laser Patterning and surface migration technologies
Conducted in collaboration with Dr. Philippe Bardet, George Washington University



Minor Investigations

- Drag reduction/Fluid Flow Modification



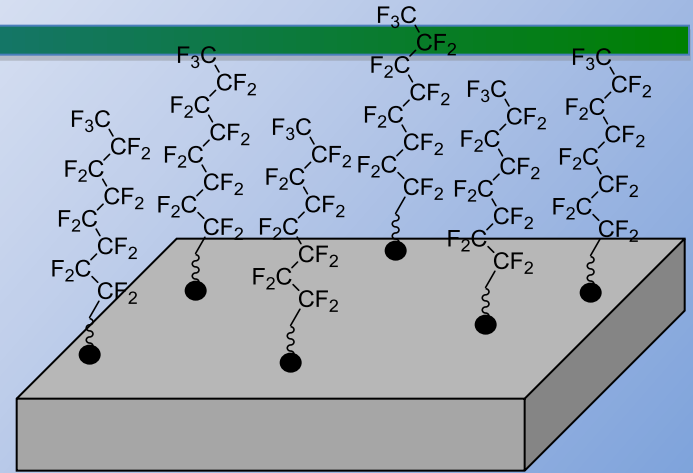
Combination of Laser Patterning and surface migration technologies
Conducted in collaboration with Dr. Philippe Bardet, George Washington University



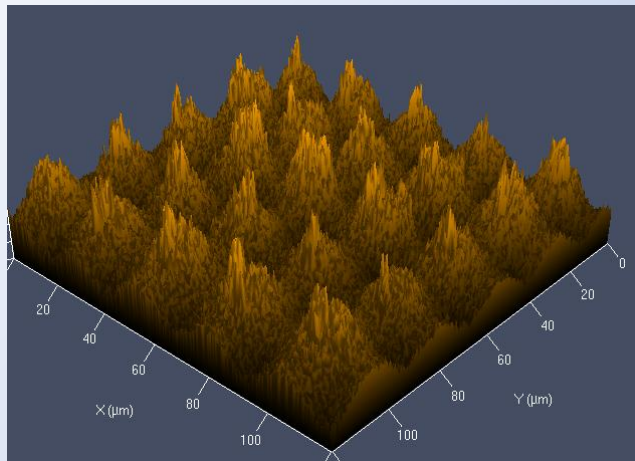
Silanated, Topographically Modified Surfaces



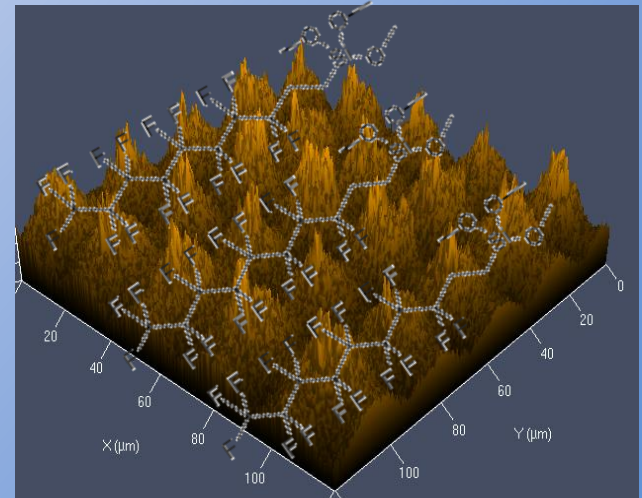
Aluminum Substrate



Low Surface Energy Aluminum Substrate



Laser Ablated Aluminum Substrate



Coated Laser Ablated Aluminum Substrate



Case Study 3: Insect and Ice Mitigation

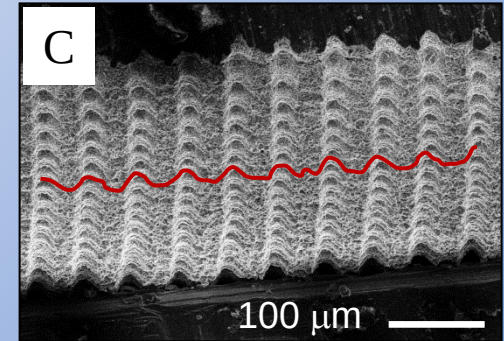
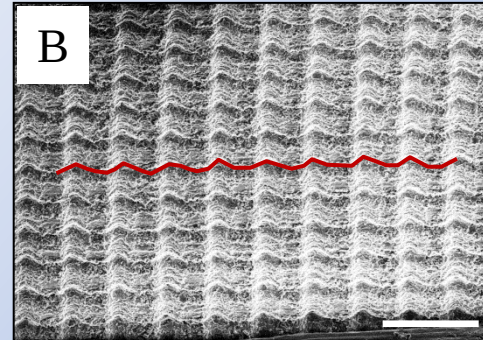
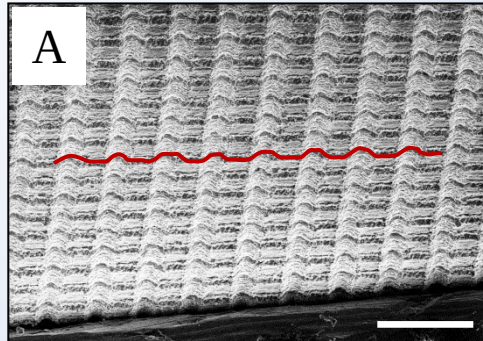
Surface	Contact Angle	Residue Area	Residue Height μm	Areal Coverage mm^2
Aluminum Control			70 ± 4	1.38 ± 0.49
Hydrophobic Coating			66 ± 4	0.71 ± 0.30
Laser Patterned			66 ± 5	1.22 ± 0.10
Coated Laser Patterned			62	0.45

Chemical
Change

Topographical
Change



Case Study 3: Insect and Ice Mitigation



Laser Energy 40 μJ

$\theta_{\text{A}}, \text{H}_2\text{O}$ 162°

65 μJ

167°

99 μJ

171°

Fruit Fly

Residue Height 60 μm

97 μm

64 μm

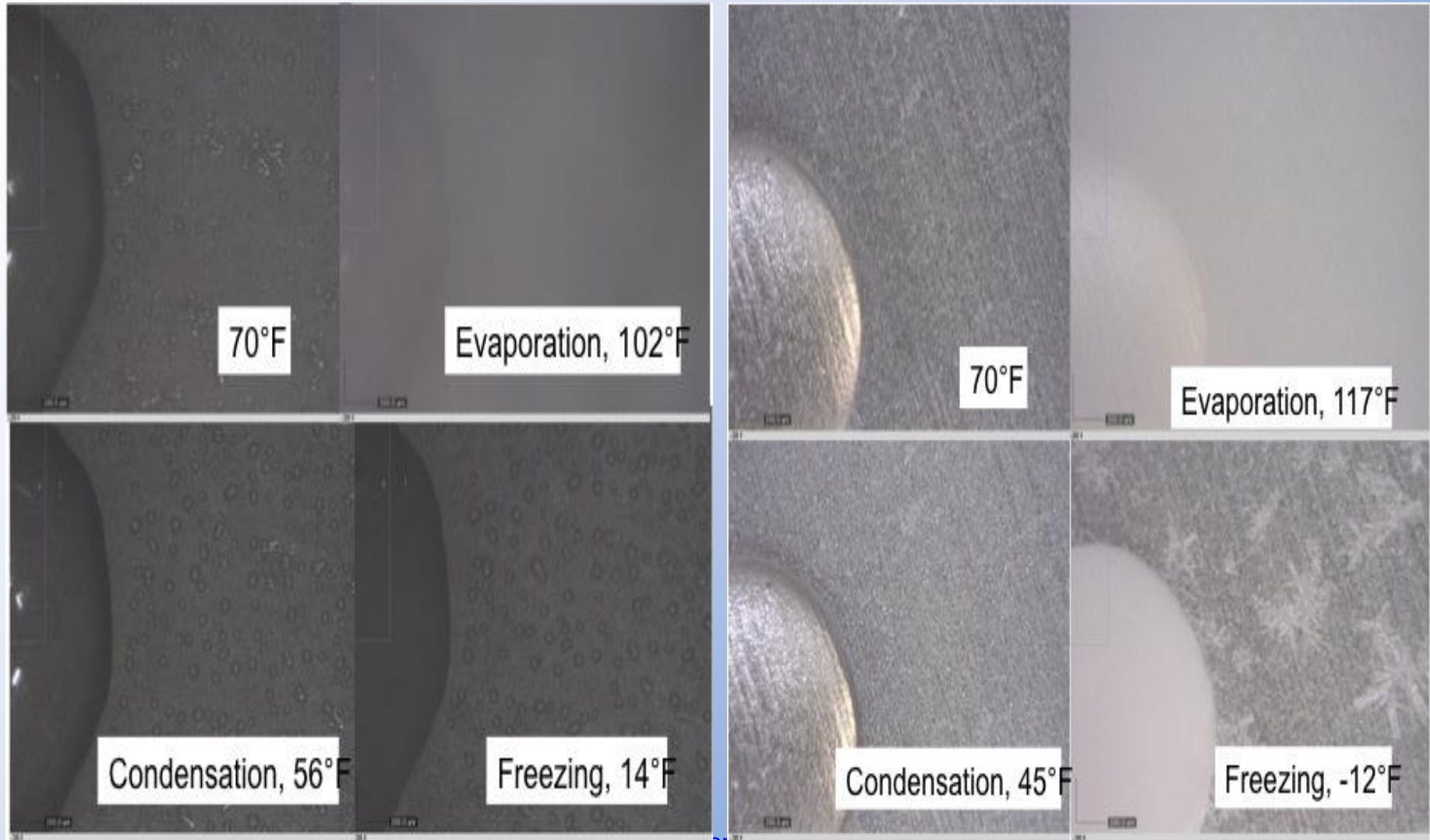
Areal Coverage 0.26 mm^2

1.43 mm^2

0.50 mm^2



Case Study 3: Insect and Ice Mitigation





Adhesion Mitigation Technology Conclusions

- Technologies for Adhesion Prevention:
 - Copoly(imide alkyl ethers)
 - Epoxy alkyl ether composites
 - Laser ablation patterning
 - Surface Topography and Silanation

- ◆ Technologies have been developed to address specific NASA mission needs
- ◆ These technologies are likely of utility for far broader applications



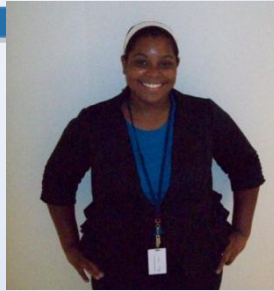
Acknowledgements



Brad Atkins



Leanna Cooper



Samantha Applin



Allison Crow



Max Verkamp



William Kim



Alexxandra
Cisotto



Michael Leonetti



Brian Koh



Jacob Keifer



Dawson Connell

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THANK YOU





Questions

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