

Fluorinated Surface Modifying Agents for Reducing Contaminant Adhesion on Aircraft Surfaces

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Georgia Southern University

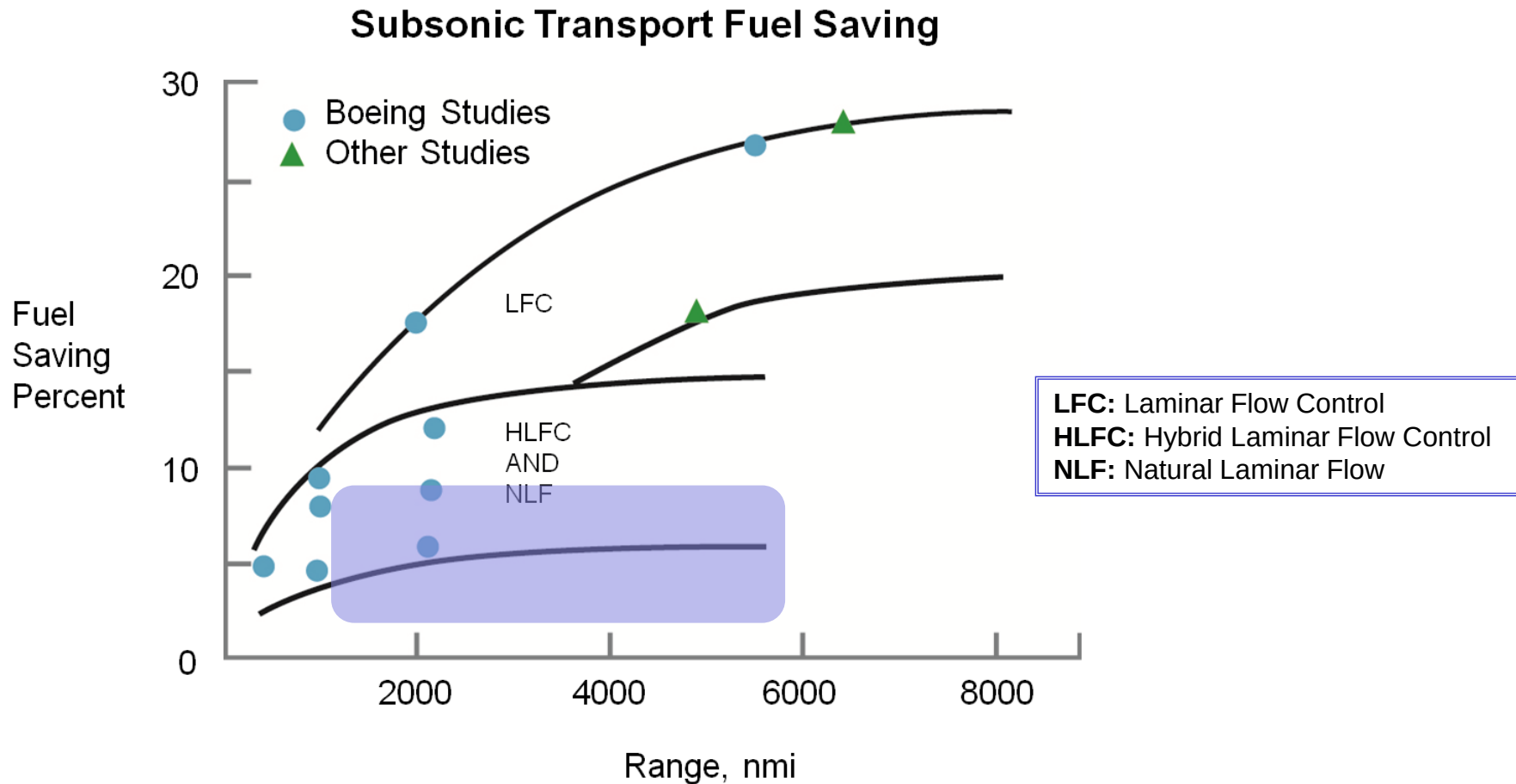
February 26, 2015



Why Study these Surfaces?



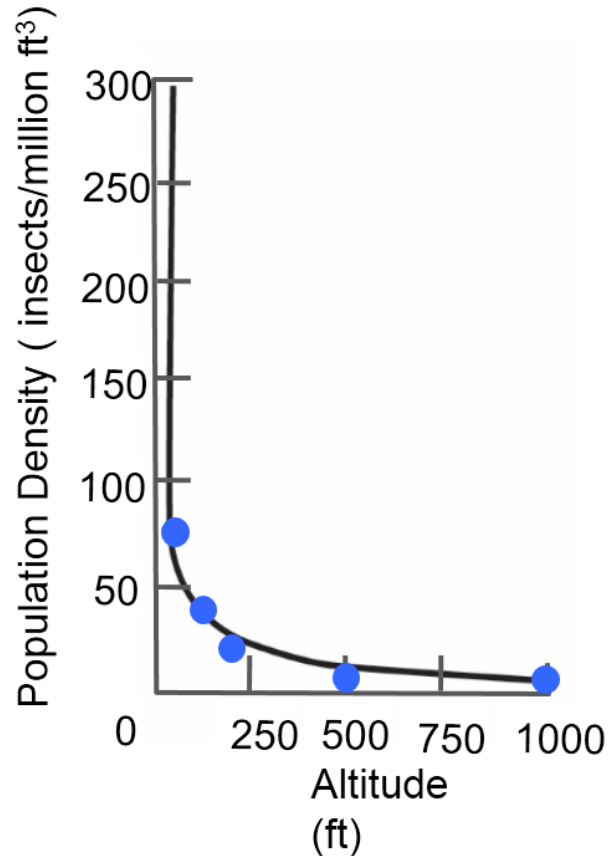
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Insect Accretion Mitigation



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NASA Dryden Flight Research Center Photo Collection
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>
NASA Photo: EC97-44358-2 Date: December 29, 1997 Photo By: Tony Landis
DC-8 Airborne Laboratory arrival at NASA Dryden



NASA Dryden Flight Research Center Photo Collection
<http://www.dfrc.nasa.gov/Gallery/Photo/index.html>
NASA Photo: ED04-0056-71 Date: March 6, 2004 Photo By: Jim Ross
NASA's DC-8 flying laboratory takes off from Juan Santamaria International Airport in San Jose, Costa Rica, on NASA's AirSAR 2004 campaign.

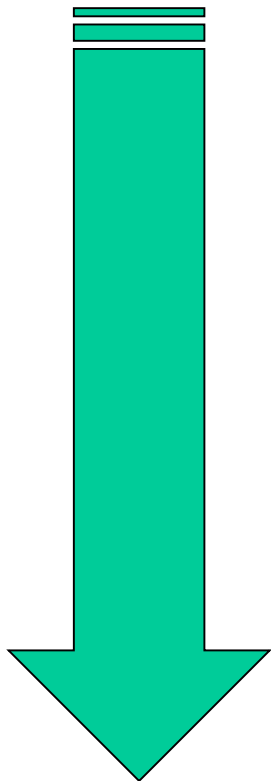
To design an engineered surface that prevents insect residue adhesion under take-off and landing conditions

Generation of Fluorinated Surfaces

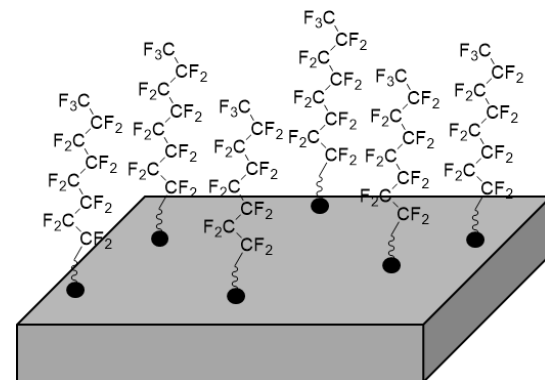


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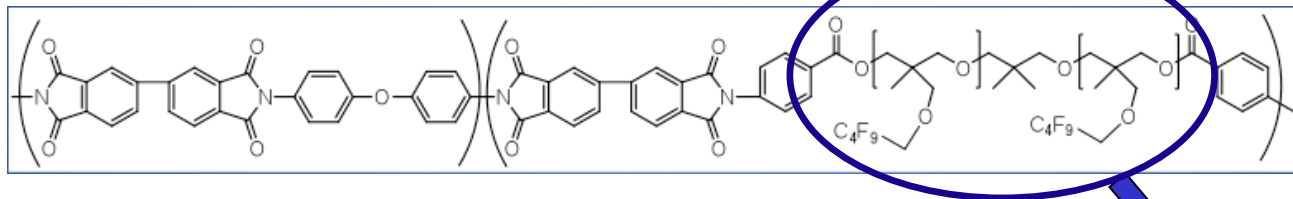
Increasing
Complexity



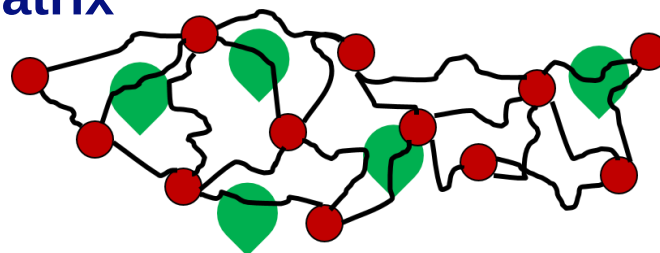
- ◆ Molecular level surface fluorination



- ◆ Surface modifying agent in a condensation polymer



- ◆ Surface modifying agent in a cross-linked matrix



A Biomimetic Adhesion Digression



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Lotus Leaf ... Superhydrophobicity



Rose Petal Effect



Common Characterization Techniques:

- Contact Angle Goniometry
- Controlled Insect Impact

Operational Environment Simulation



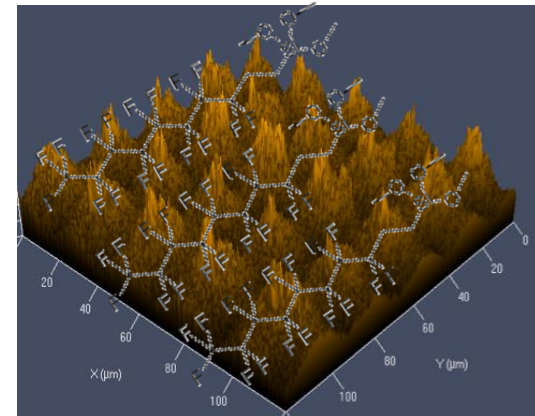
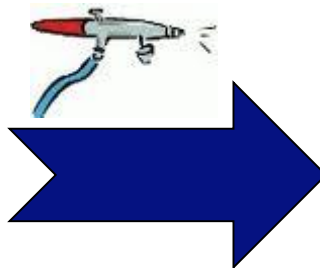
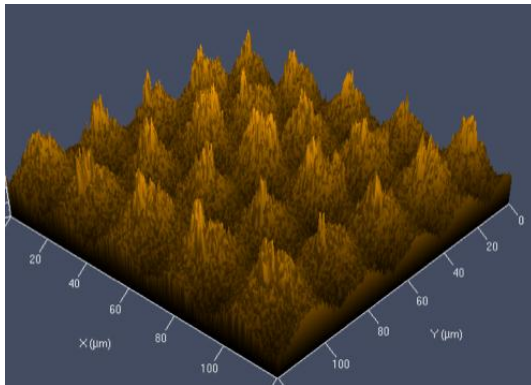
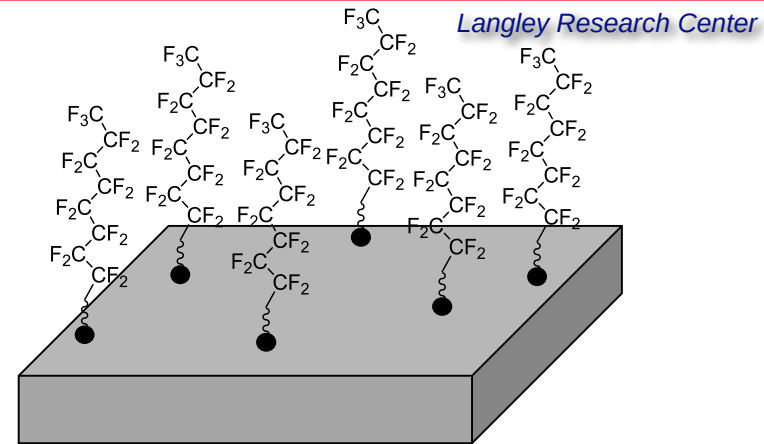
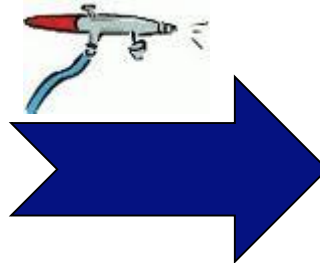
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Flightless fruit fly (*drosophila melanogaster*)



Bench-top Wind Tunnel

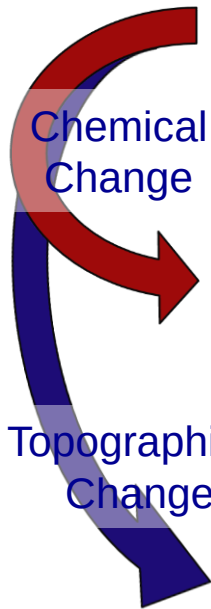


- ## ◆ Reaction between surface hydroxyl functionalities and perfluorinated triethoxysilane

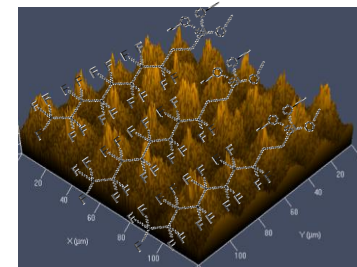
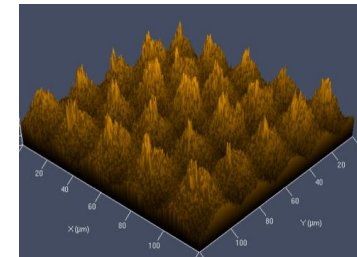
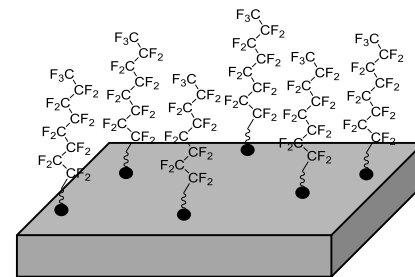
Part I Surface Fluorination



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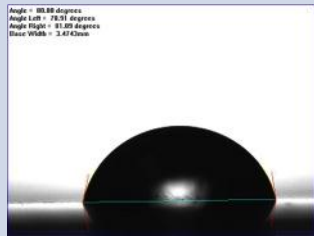
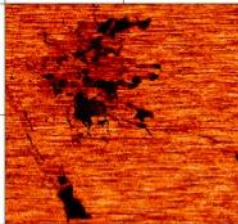
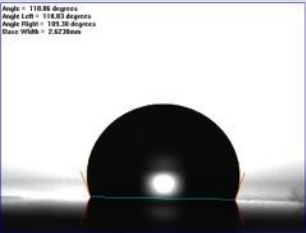
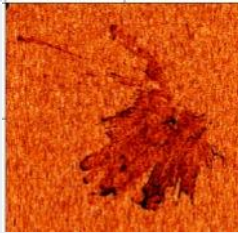
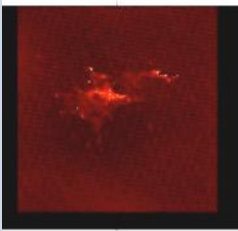
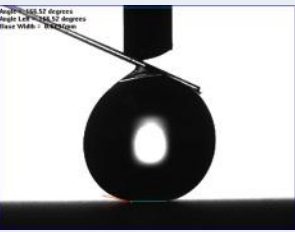
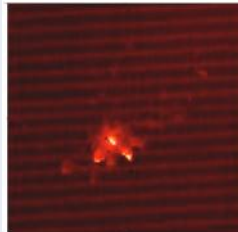
Surface	Contact Angle
Aluminum Control	Angle = 80.89 degrees Angle Left = 75.51 degrees Angle Right = 81.87 degrees Base Width = 3.412mm
Hydrophobic Coating	Angle = 110.96 degrees Angle Left = 108.82 degrees Angle Right = 109.38 degrees Base Width = 3.823mm
Laser Patterned	
Coated Laser Patterned	Angle = 80.52 degrees Angle Left = 75.51 degrees Angle Right = 81.87 degrees Base Width = 3.412mm



Part I Surface Fluorination



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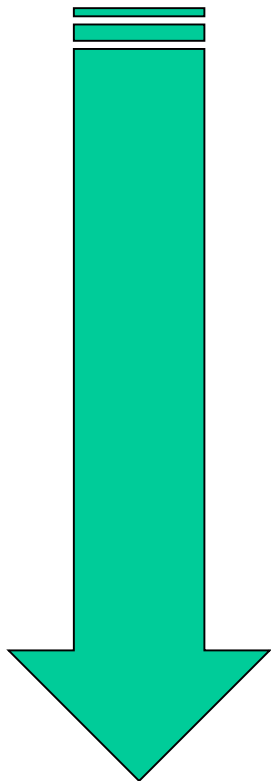
Surface	Contact Angle	Residue Area
Aluminum Control		
Hydrophobic Coating		
Laser Patterned		
Coated Laser Patterned		

Generation of Fluorinated Surfaces

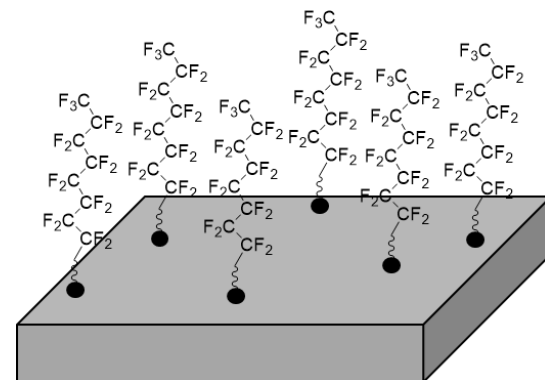


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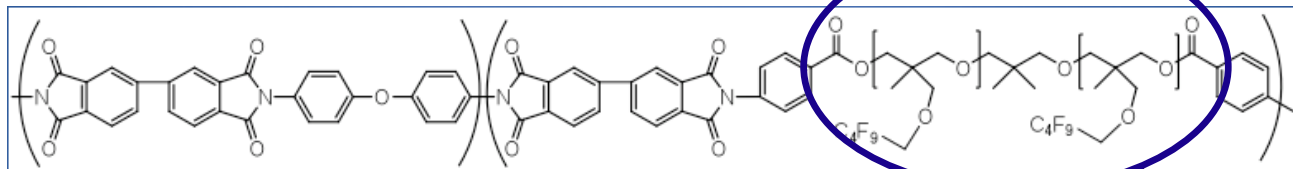
Increasing
Complexity



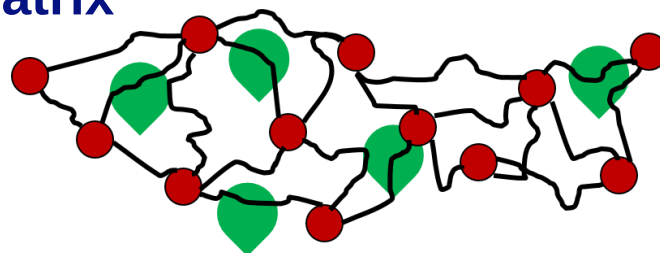
- ◆ Molecular level surface fluorination



- ◆ Surface modifying agent in a condensation polymer

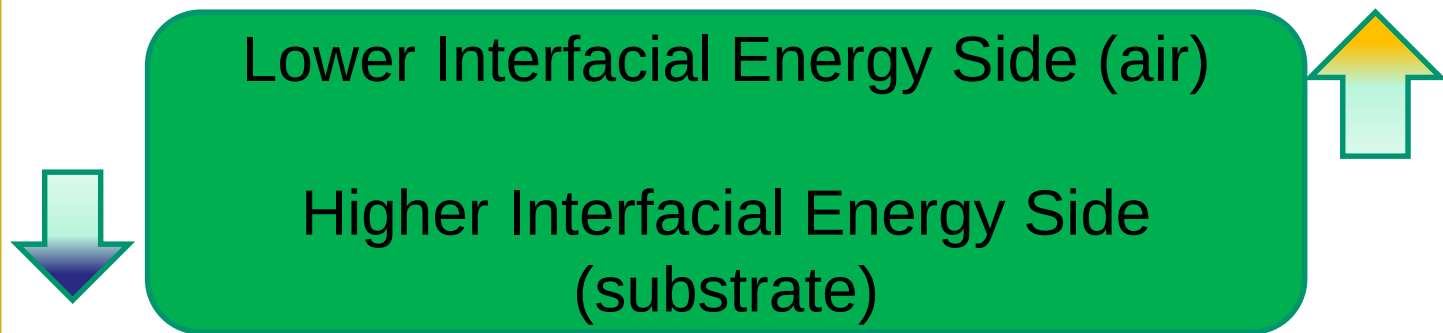


- ◆ Surface modifying agent in a cross-linked matrix



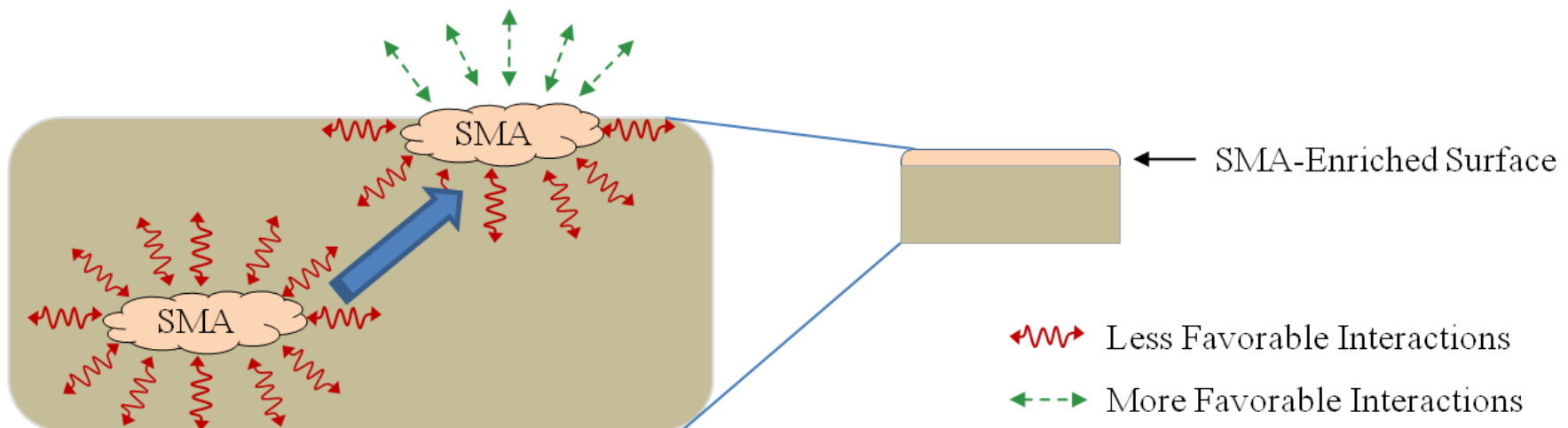
- ◆ Surface modifying agents (SMA)s are great examples of entropy vs enthalpy

Thermodynamic Response of SMA

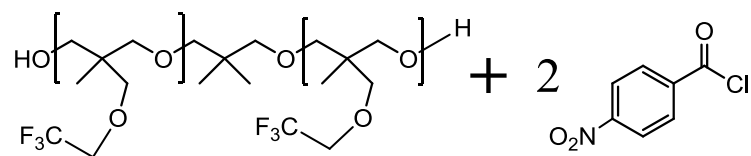


Arrows indicate enthalpy-driven migration of **LOW** and **HIGH** surface energy components

- ◆ Surface modifying agents (SMA)s are great examples of entropy vs enthalpy

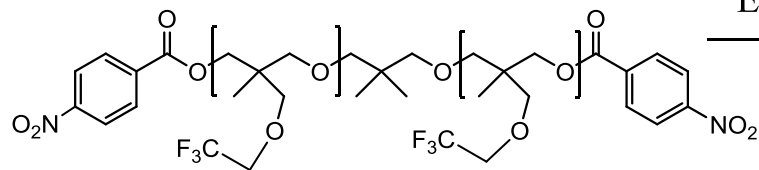


◆ Hydroxyl-terminated, oxetane-derived oligomers with small chain length, fluorinated side-chains (Omnova)



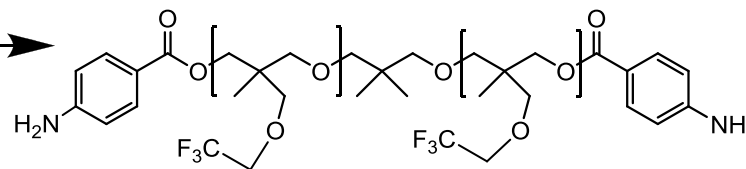
I

NEt₃
Toluene
Δ



II

Pd/C, H₂
EtOH



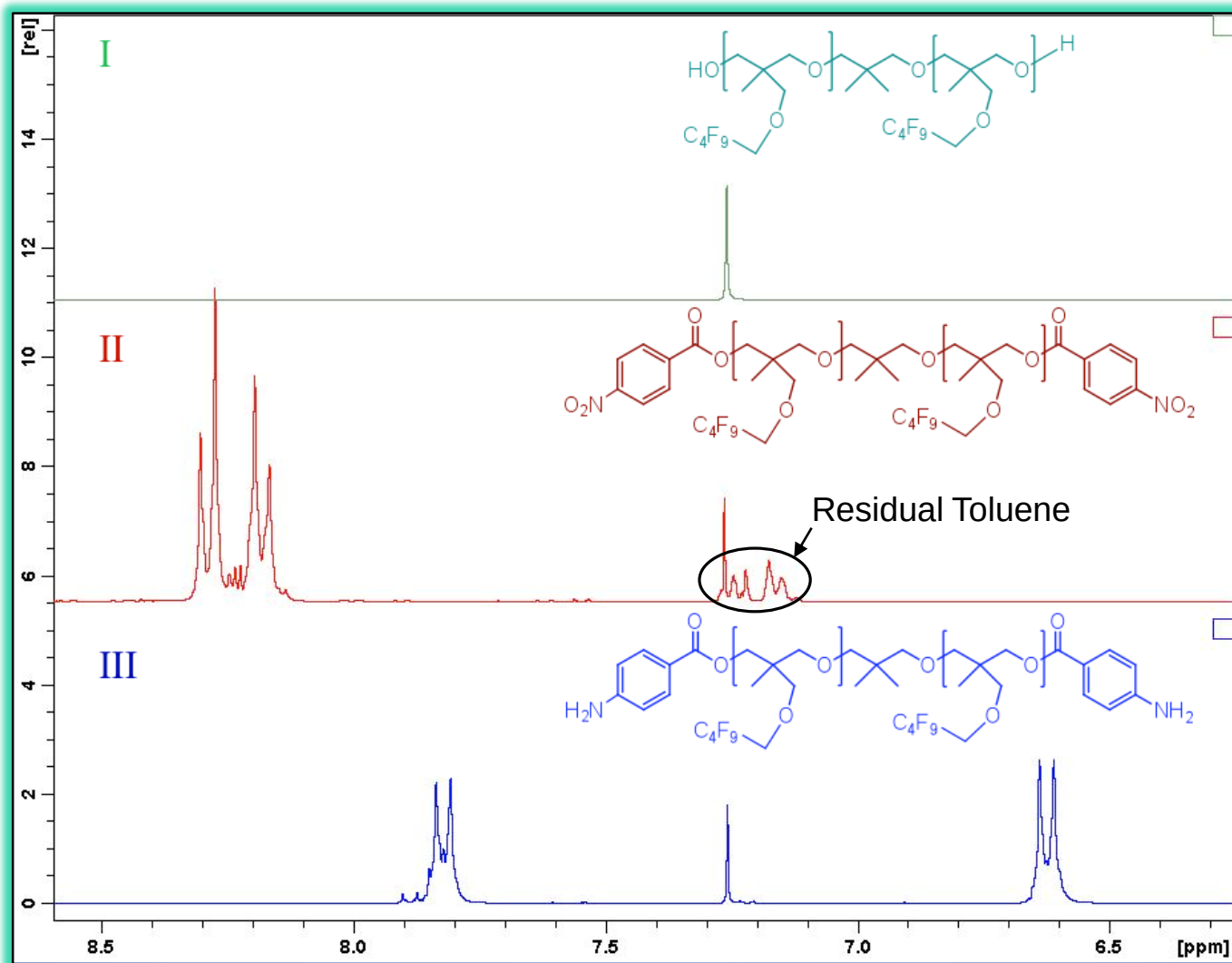
III

AEFO	F Side Chain	OH-Terminated (g/mol)	NO ₂ -Terminated (g/mol)	NH ₂ -Terminated (g/mol)
PF636	CF ₃	1150	1450	1310
PF656	C ₂ F ₅	1490	1570	1530
PF154N	C ₂ F ₅	3460	3060	3200
PF7002	C ₄ F ₉	1670	1770	1640
PF6320	CF ₃	3480	3580	4740

Part II SMAs in Condensation Polymers



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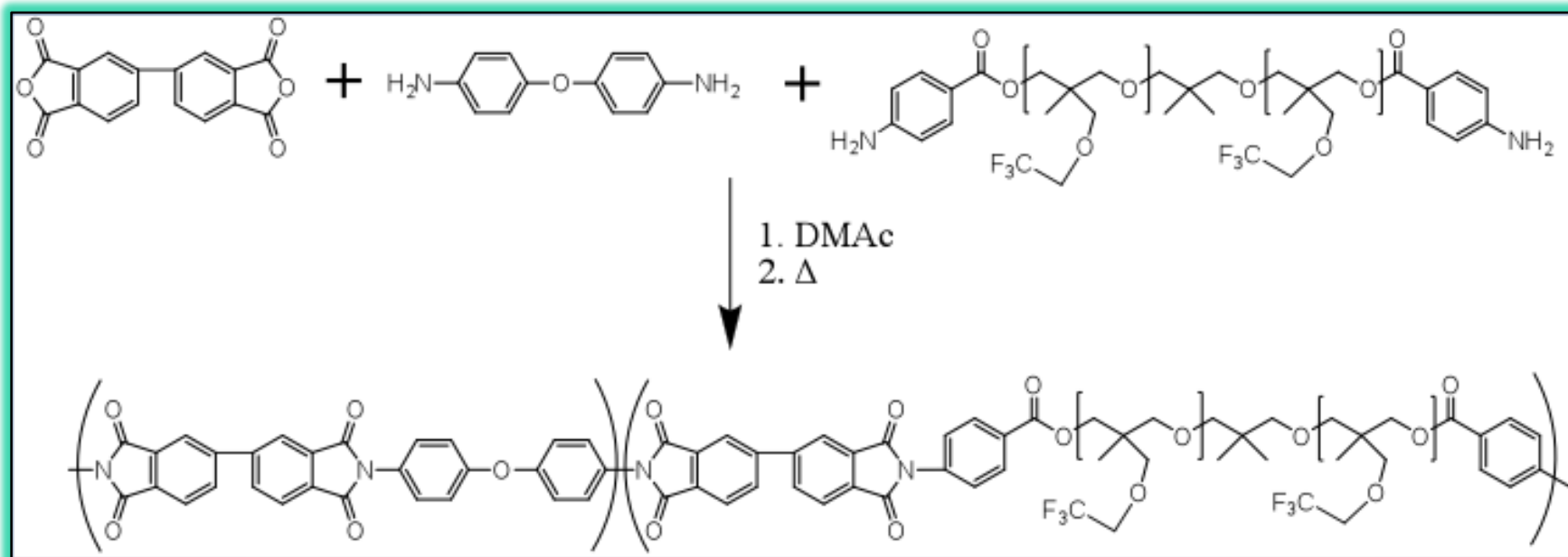


Spectra collected on a Bruker 300 MHz instrument in CDCl_3

Part II SMAs in Condensation Polymers



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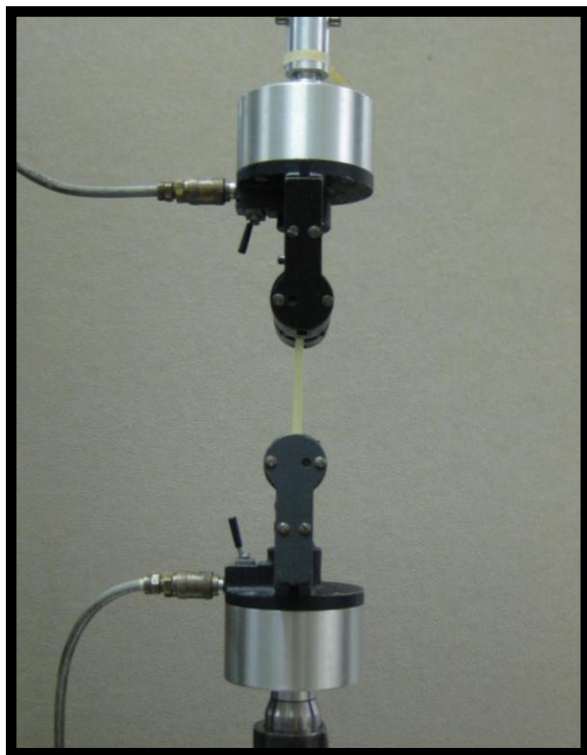
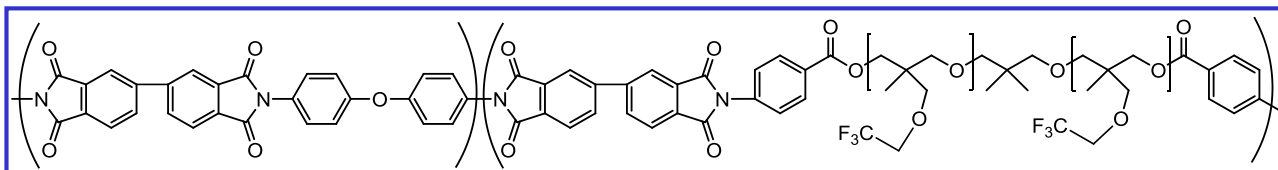


- ◆ Free-standing films were solution cast on plate glass
- ◆ Imidization was performed thermally in an N_2 environment at a final temperature of 250 °C
- ◆ Completion of reaction confirmed by ATR-FTIR

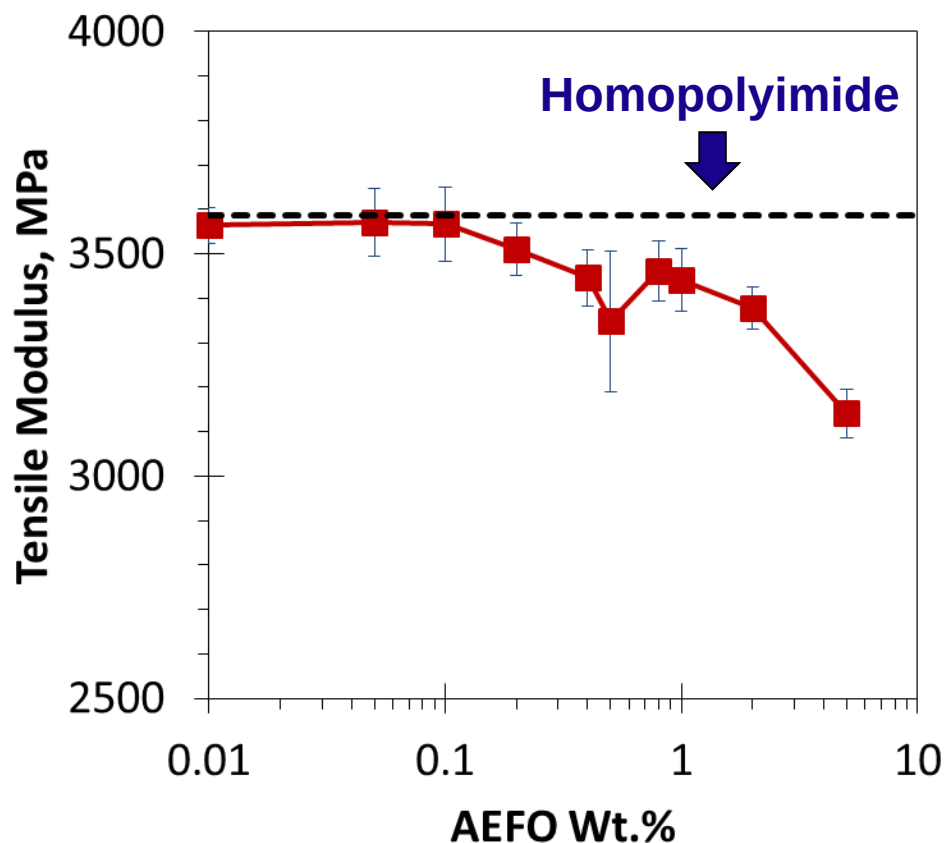
Part II SMAs in Condensation Polymers



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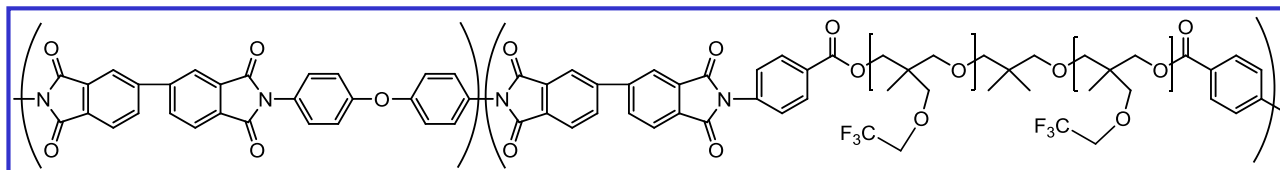
Tensile Test Rig



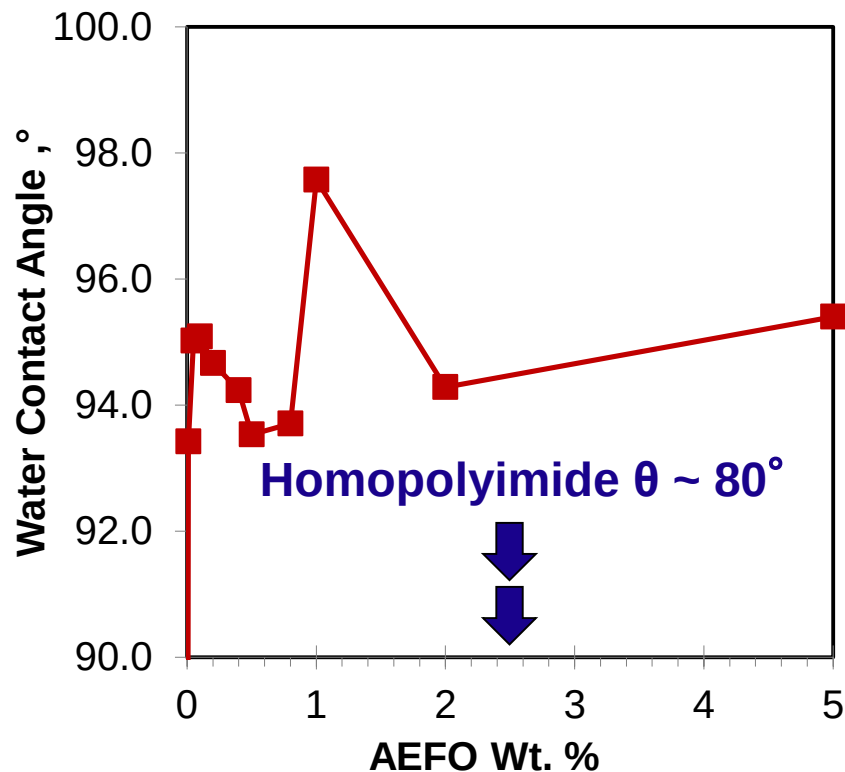
Part II SMAs in Condensation Polymers



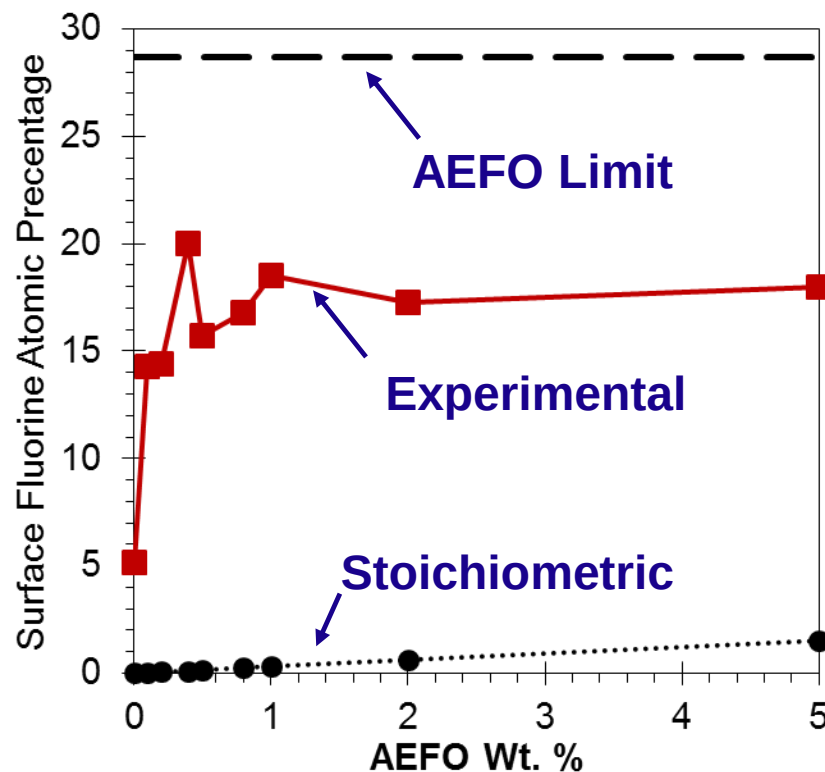
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Water Contact Angle



XPS



Part II SMAs in Condensation Polymers



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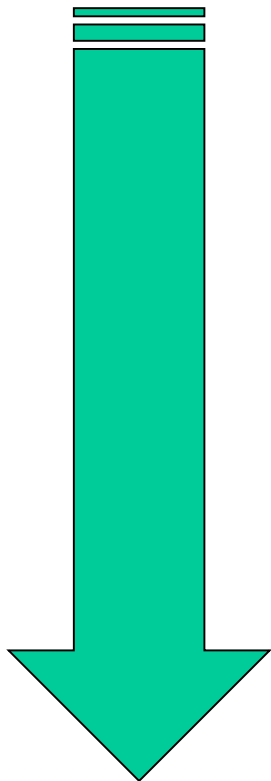


Generation of Fluorinated Surfaces

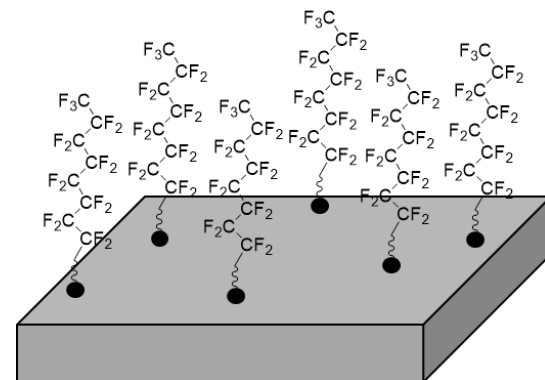


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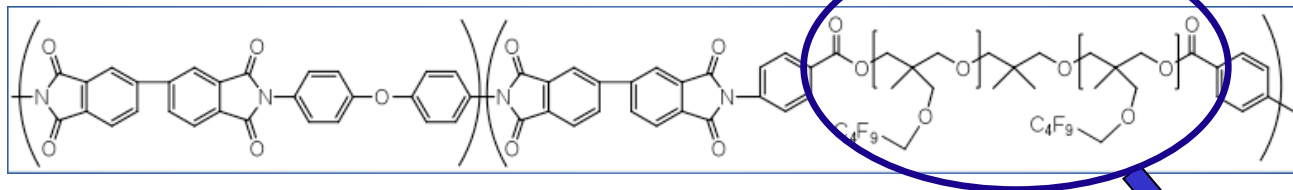
Increasing
Complexity



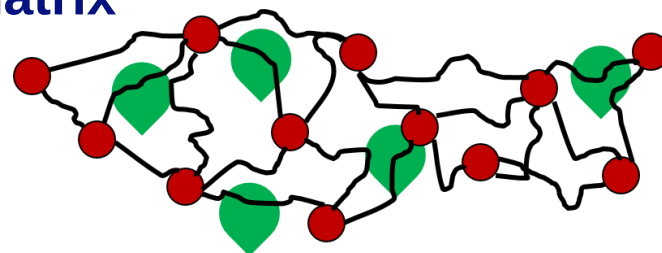
- ◆ Molecular level surface fluorination



- ◆ Surface modifying agent in a condensation polymer



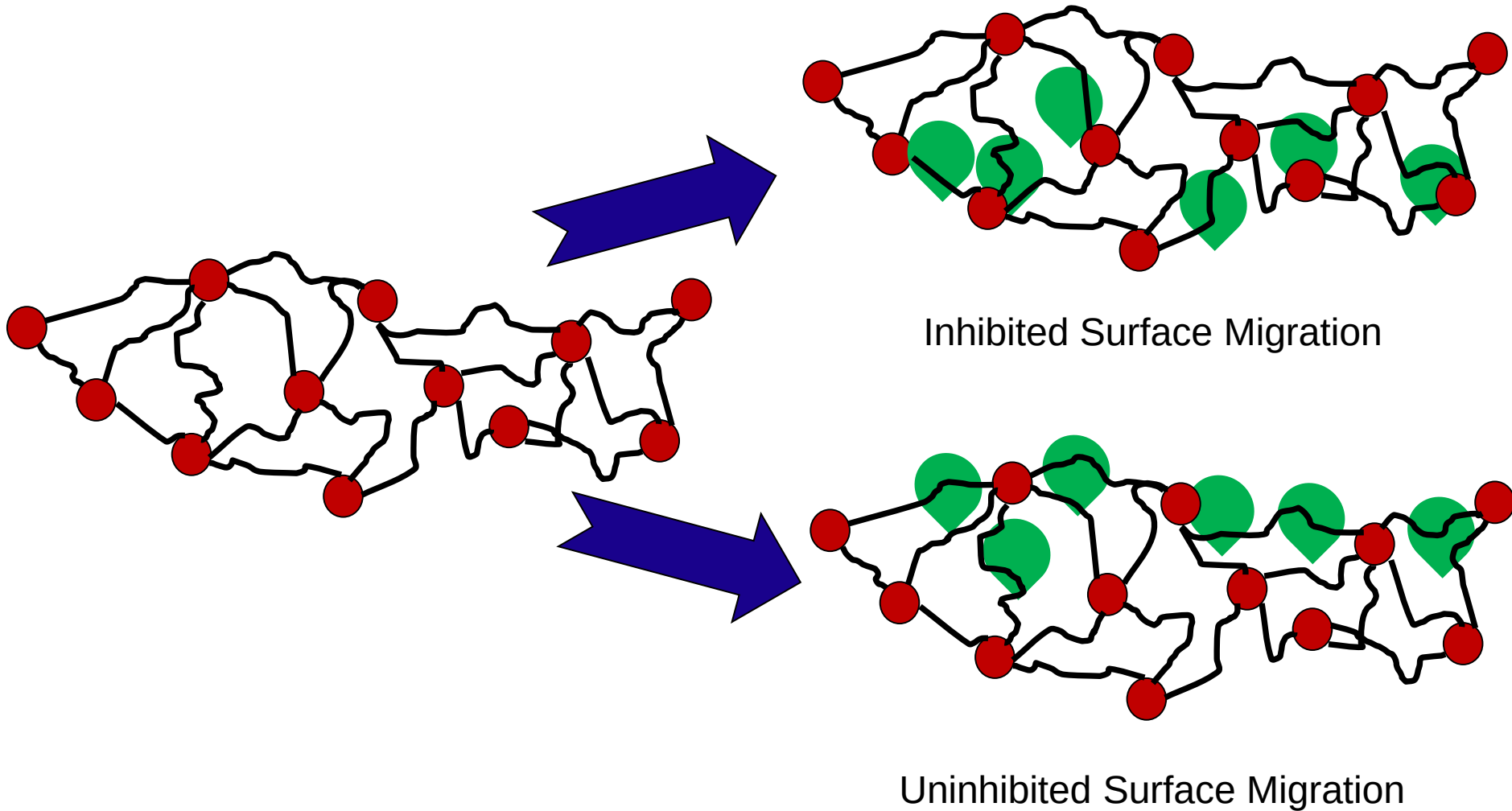
- ◆ Surface modifying agent in a cross-linked matrix



Part III Epoxy Cross-linked System



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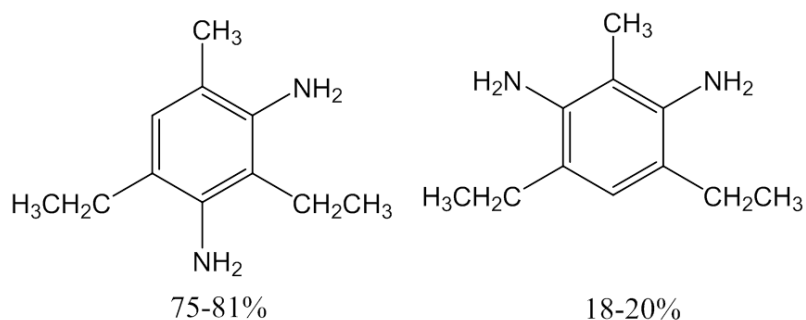


Part III Epoxy Cross-linked System

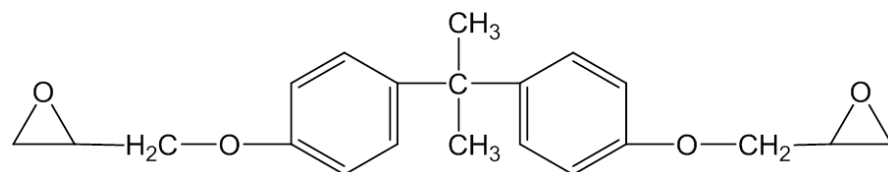


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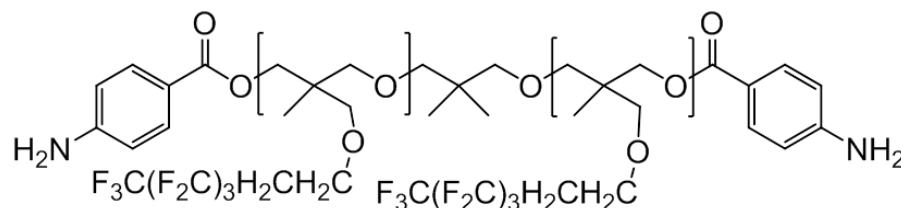
◆ Epoxy



Ethacure[®] 100



D.E.R.[™] 331 (DGEBA)



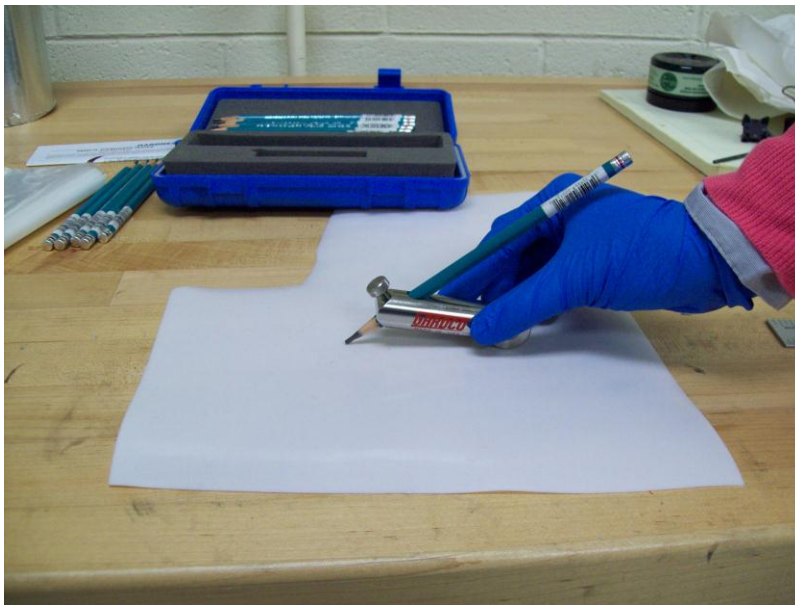
Fluorinated Aliphatic Ether (AEFO)

◆ Particulates

Particulate	Diameter, nm	Note
SiO ₂	7	Fumed Silica, hydrophilic surface
MoS ₂	2,000	Solid lubricant

- ◆ Solutions generated in methyl ethyl ketone
- ◆ Particulate loadings varied from 0 – 25 wt%
- ◆ Sonication used to improve dispersion

Durability Characterization: Pencil Hardness Test



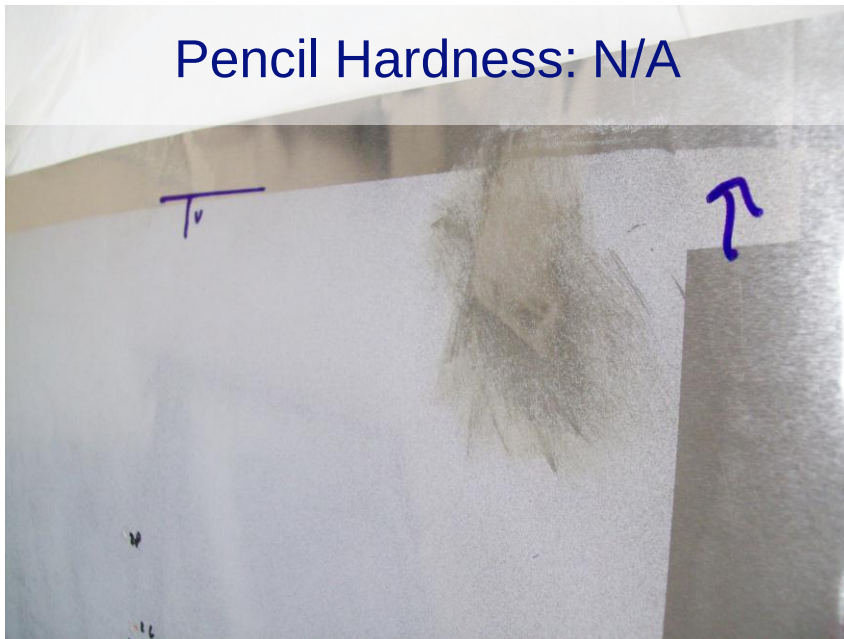
Part III Epoxy Cross-linked System



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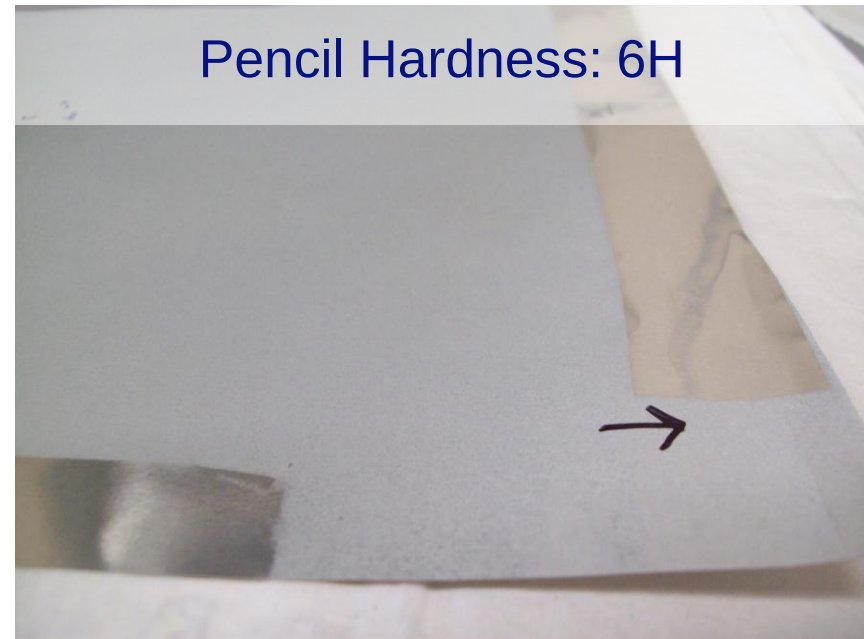
Copoly(imide alkyl ether)

Linear Polymeric System



Epoxy Nanocomposite

Cross-linked Polymeric System

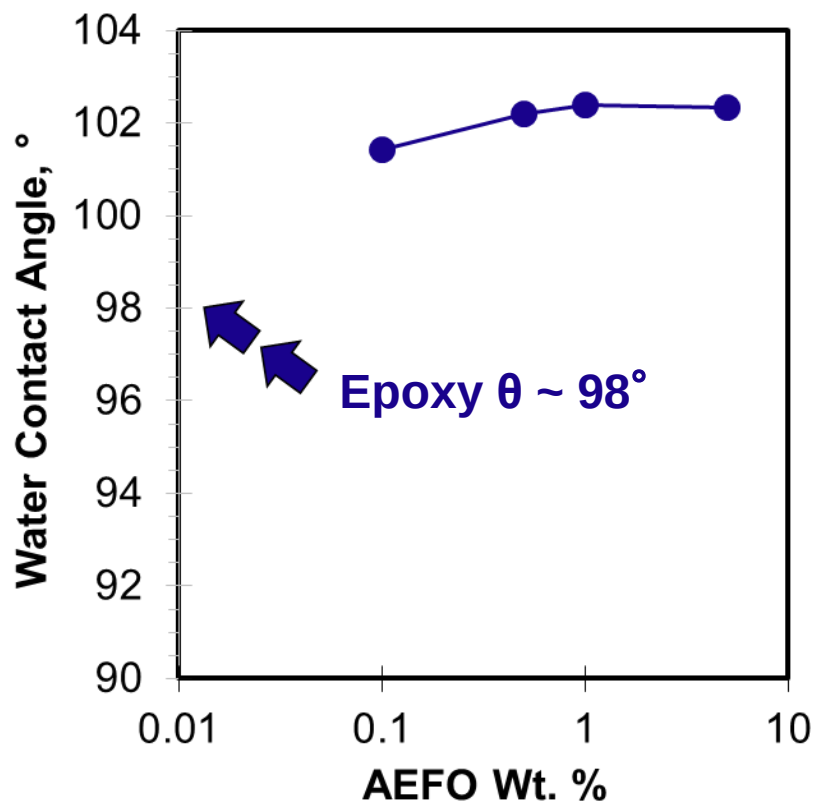


Part III Epoxy Cross-linked System

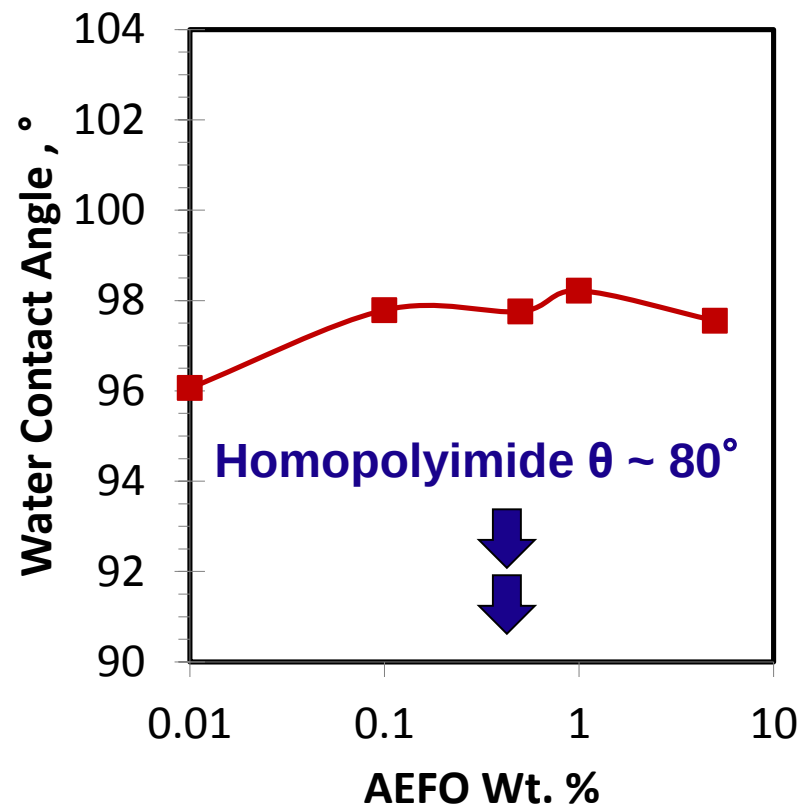


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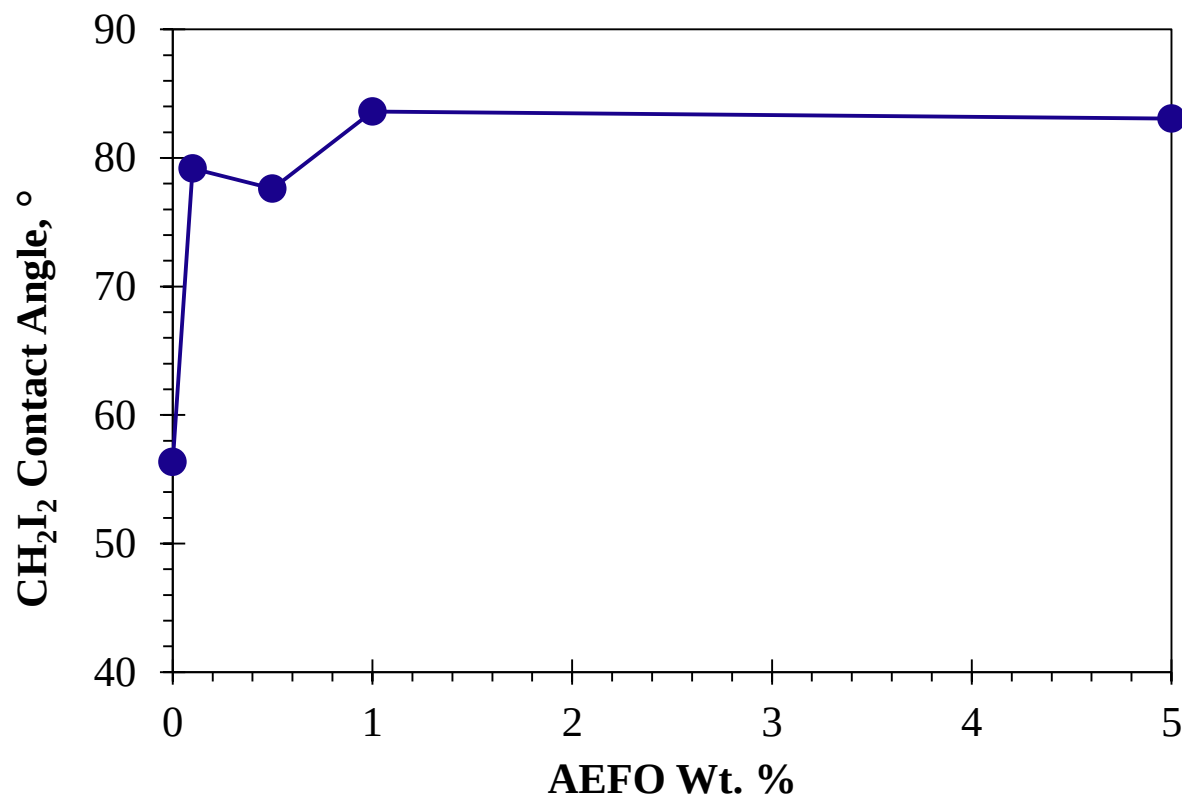
Water Contact Angle, Epoxy Matrix



Water Contact Angle, Polyimide Matrix



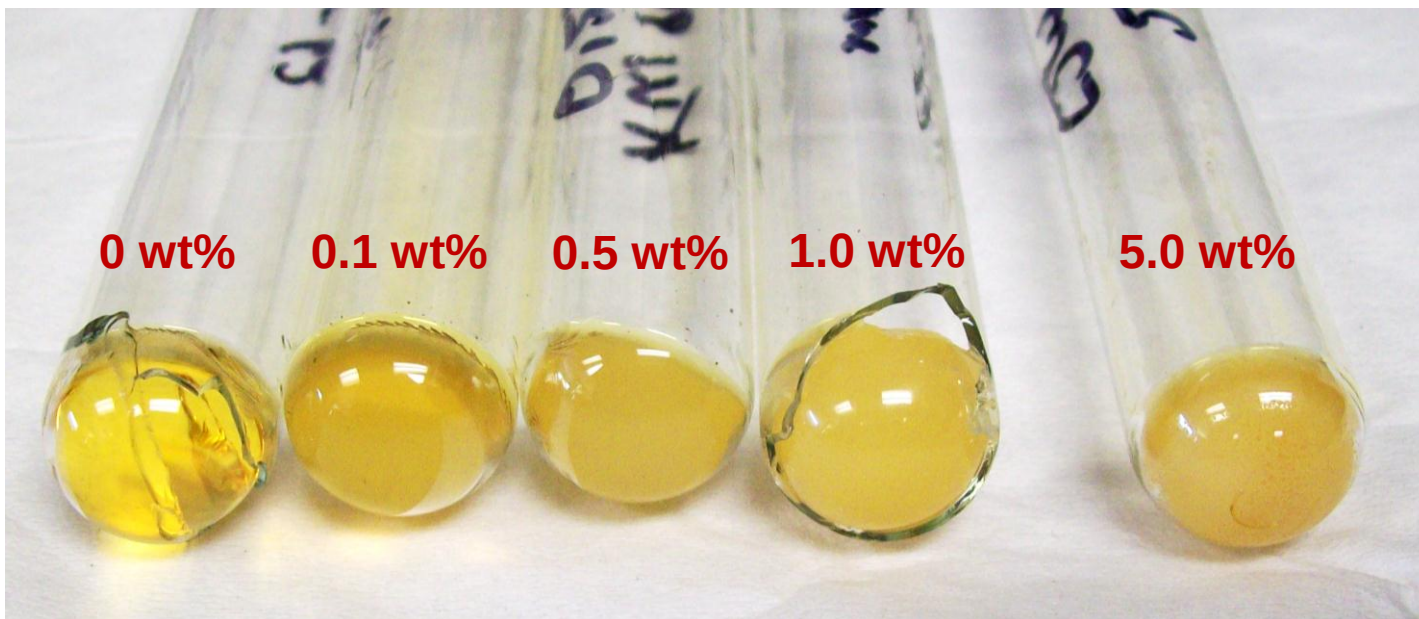
Methylene Iodide Contact Angle Data



Part III Epoxy Cross-linked System



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AEFO Loading

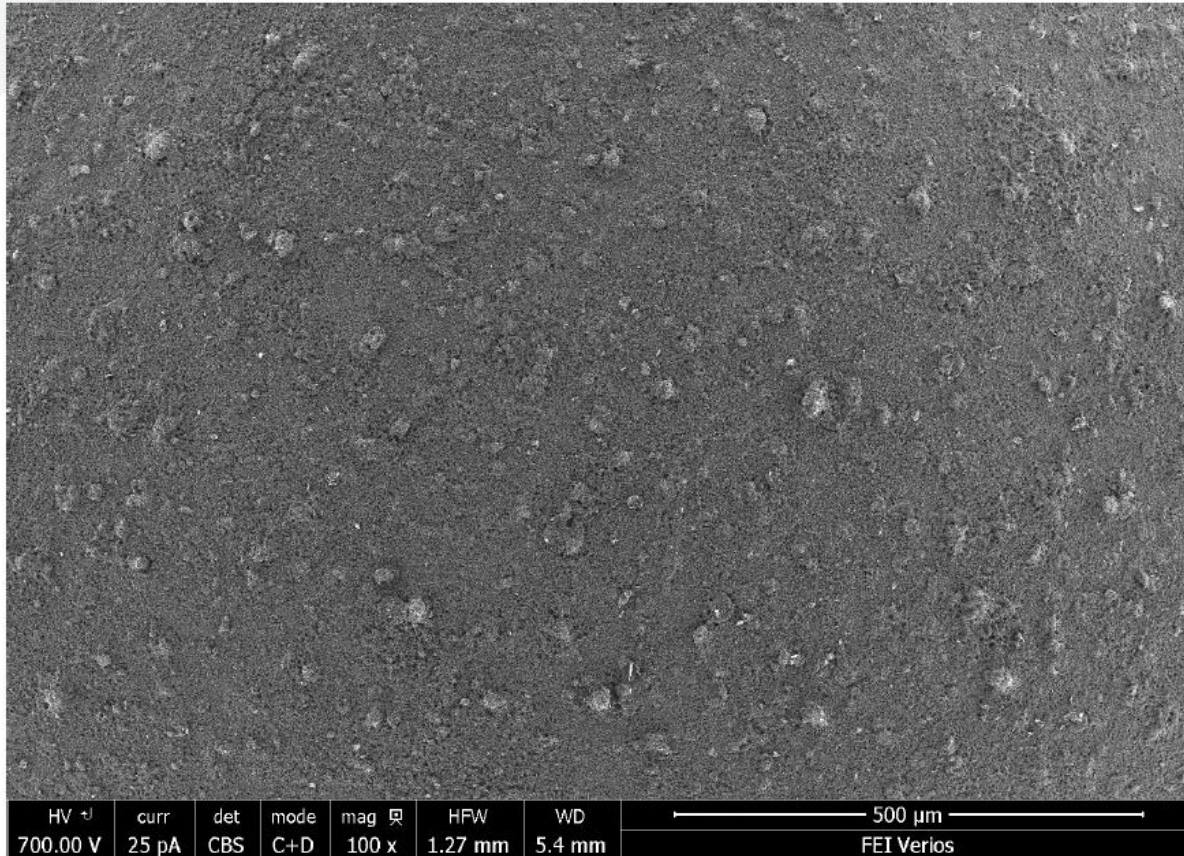


Transparency

Part III Epoxy Cross-linked System



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Representative Mixed Filler (MoS_2 and SiO_2) Epoxy Particulate Composite

Part III Epoxy Cross-linked System



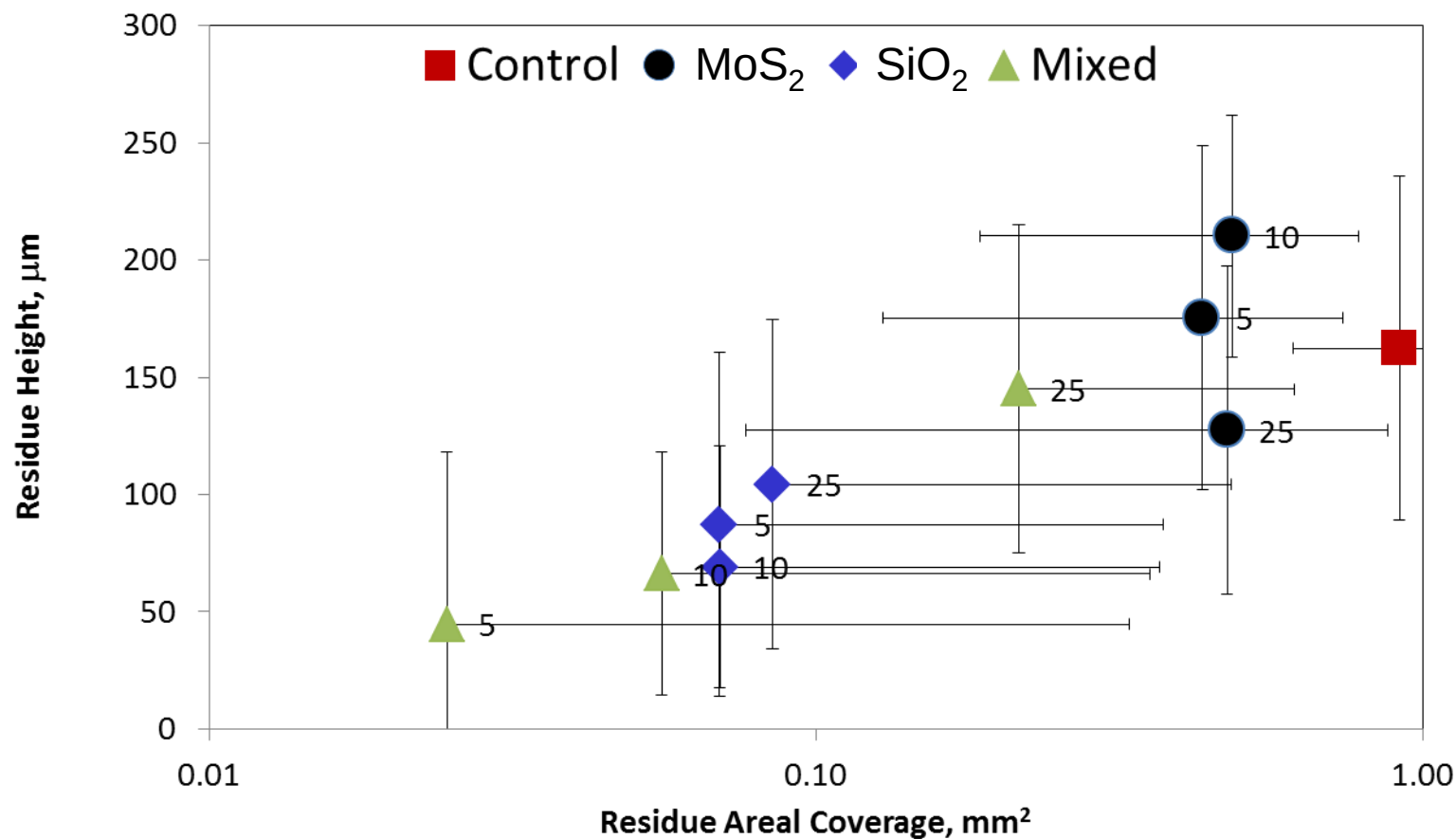
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Part III Epoxy Cross-linked System



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◆ Summary

- Generation of insect adhesion mitigation surface evolution:
 - Surface modified aluminum: controlled surface chemistry and topography to minimize residue adhesion
 - Copoly(imide alkyl ether) surfaces: surface modifying agents enabled surface chemical modification without significant compromise of bulk properties
 - Epoxy cross-linked systems:
 - Appropriate mechanical properties and durability for the service environment must be considered
 - Promising surface properties observed in previous coatings can be translated to these more complex systems

◆ Future Work

- In-depth microscopic and spectroscopy characterization of epoxy nanocomposite surfaces including XPS analysis of filled and unfilled systems
- Further identification of coating formulations for improved residue adhesion mitigation and environmental durability
- Demonstration of coating capabilities on EcoDemonstrator in 2015

Acknowledgements



Langley Research Center

◆ NASA LaRC Team:

- ◆ Emilie J. Siochi (PI)
- ◆ Joseph G. Smith Jr., John W. Connell, John M. Gardner (NASA)
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- ◆ Ronald K. Penner (Science and Technology Corporation)

◆ BART Studies:

- ◆ Dan Neuhart, Marlyn Andino, Donald Day

◆ Scientific Discussion:

- ◆ Rudy King, Tony Washburn

