



Engineered Interfaces in Extruded Polyphenylsulfone-Boron Nitride Composite Insulation

4th IEEE International Conference on Dielectrics 2022
Palermo, Italy

Tiffany S. Williams^{1}, Baochau Nguyen^{2,1}, Andrew Woodworth¹,
Marisabel Kelly¹*

¹NASA Glenn Research Center
Materials Chemistry and Physics Branch
Cleveland, Ohio, USA

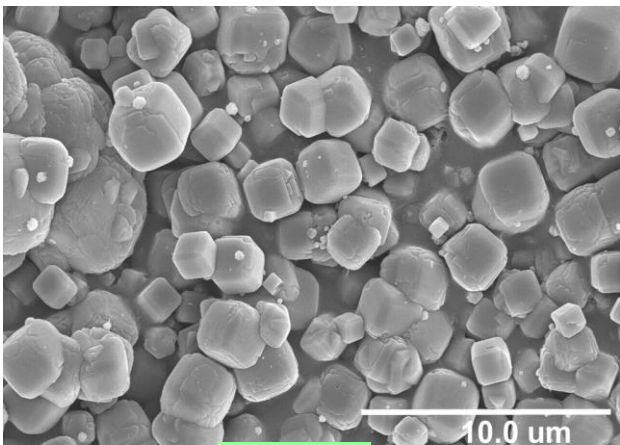
Tiffany.S.Williams@nasa.gov

²University Space Research Association (USRA)
Cleveland, Ohio, USA

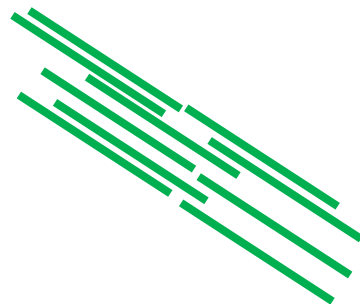


Composite Electrical Insulation

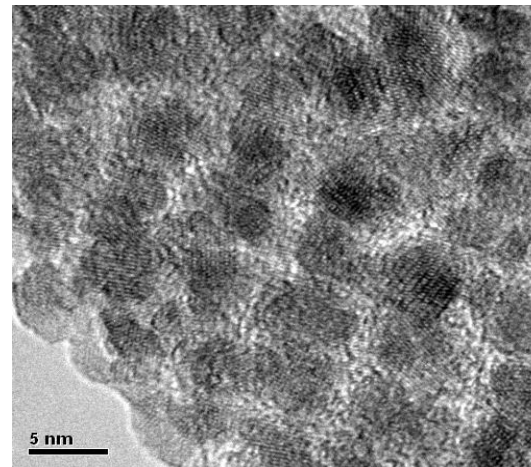
- Low thermal conductivity organic polymers prone to degradation due to heat buildup
- Electrified aircraft environment: higher operating voltages, temperatures, and frequencies
- Composite insulation offers ability to improve lifetime + enhanced dielectric and thermal characteristics
- Variations among common inorganic fillers for high voltage insulation
 - Composition: SiO_2 , TiO_2 , Al_2O_3 , ZnO , MgO , **BN, AlN**, Si_3N_4 , SiC
 - Shape
 - Size (micronized, nano, or both)



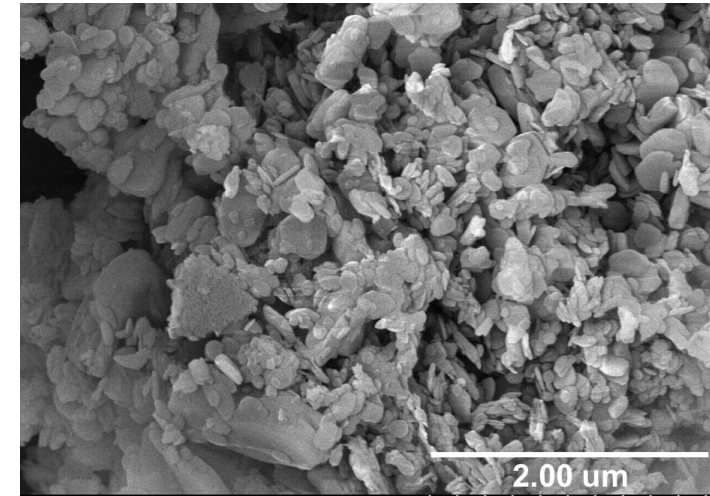
Cubic



Rod



Spherical



Platelet



Composite Electrical Insulation

- Optimal properties of composites are governed by quality of interfaces
 - Chemical methods
 - Silane coupling agents
 - Small group functionalization at surface
 - Physical
 - Nanoscale fillers believed to enhance polymer filler interactions
 - Proper mixing method (sonication, melt blending, solution mixing)

Objective: To investigate how the filler incorporation strategy affects the quality of the interfaces → dielectric properties and thermal conductivity

Thermally Conductive Composite Insulation

- **Matrix: Polyphenylsulfone (PPSU)**

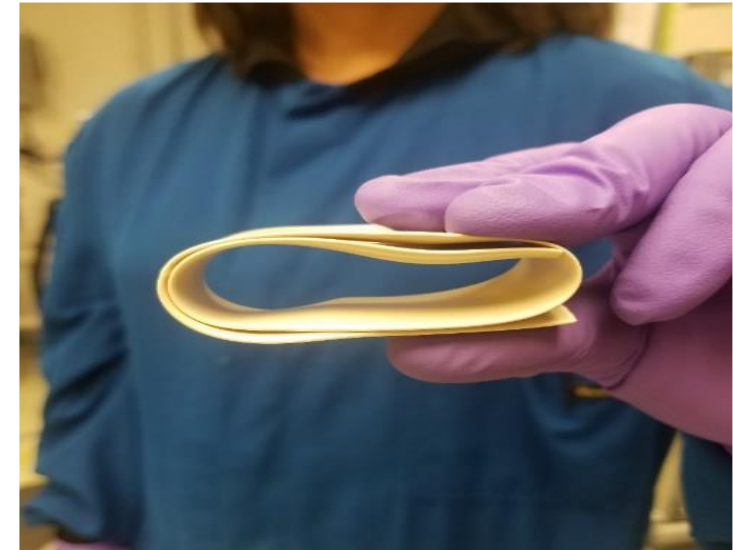
- High toughness and impact resistance
- 230 °C T_g
- Heat deflection temperature of ~207 °C
- Inherently flame retardant
- Chemical resistance
- Low moisture absorption
- Limited to 180 °C continuous operating temperature
- Not UV stable

- **Filler: Hexagonal boron nitride (hBN)**

- Exceptionally high thermal conductivity
- Electrically insulating
- Radiation shielding

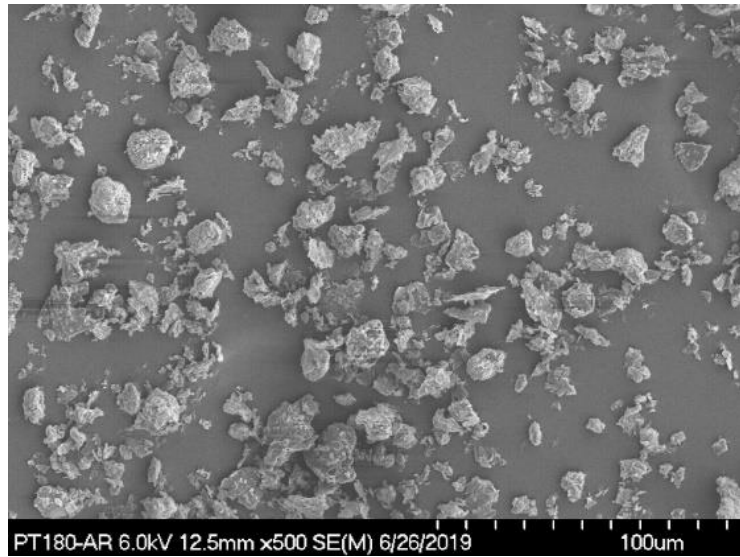


PPSU-hBN composite ribbon extrusion



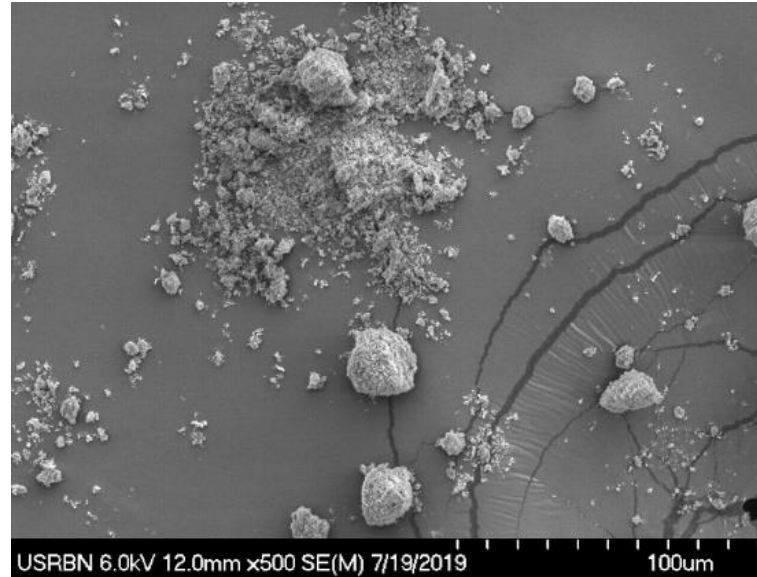
High-bend radius

Thermally Conductive Composite Insulation



Micronized hBN

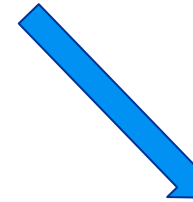
+



nano-hBN



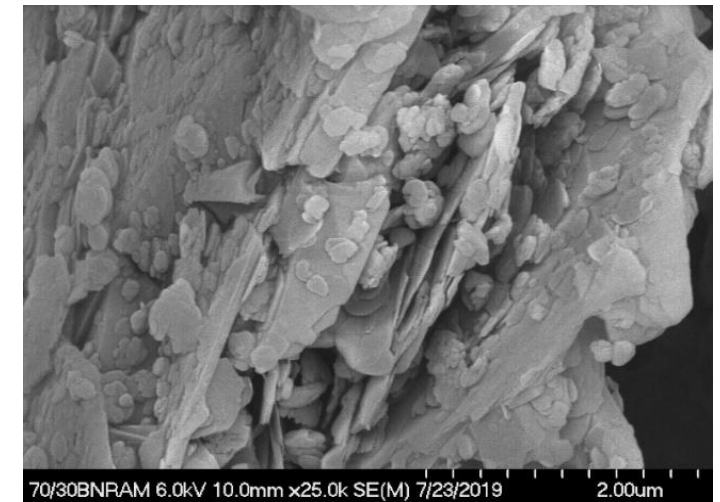
Micronized + nano-hBN



Virgin PPSU



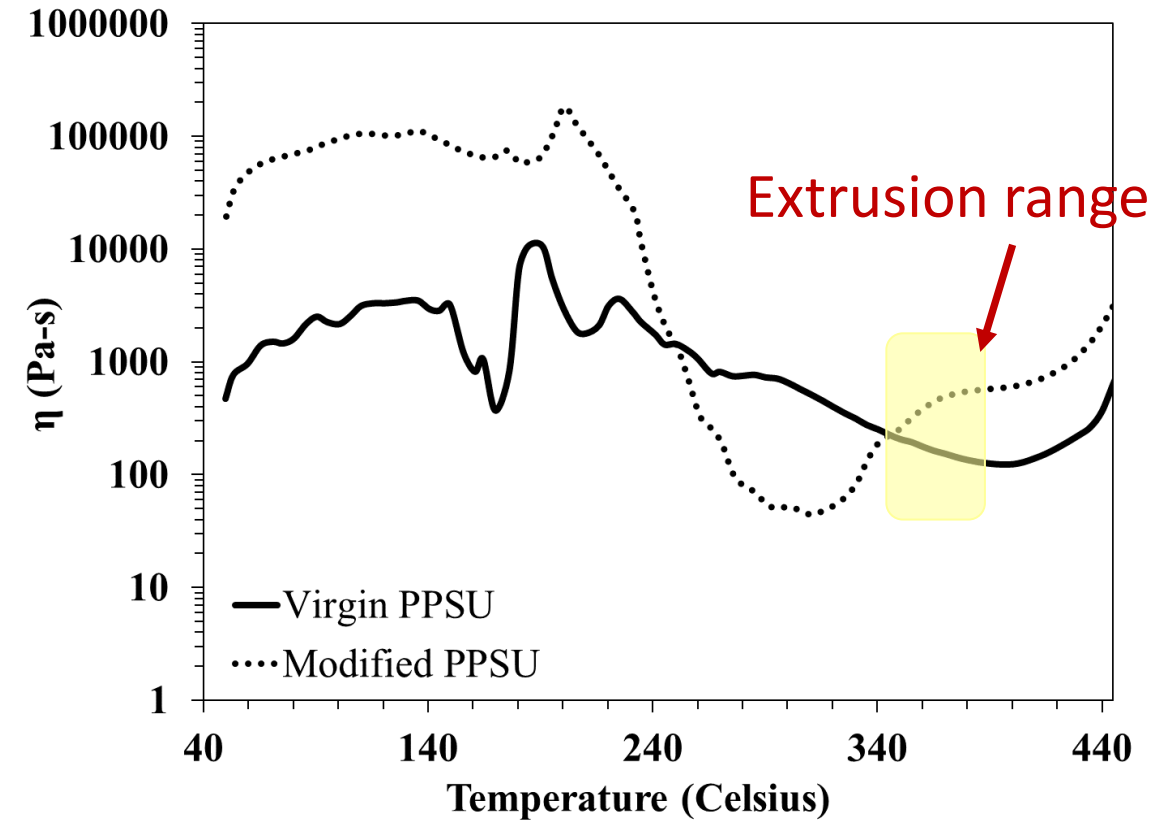
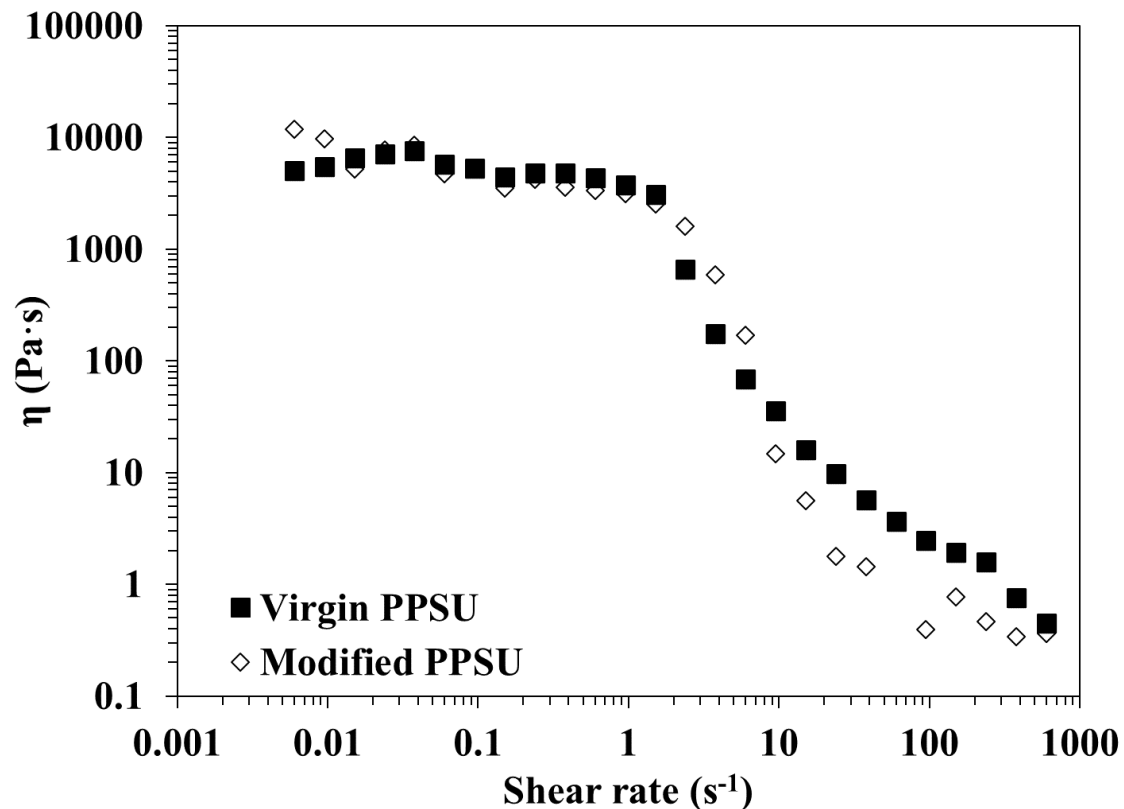
Modified PPSU



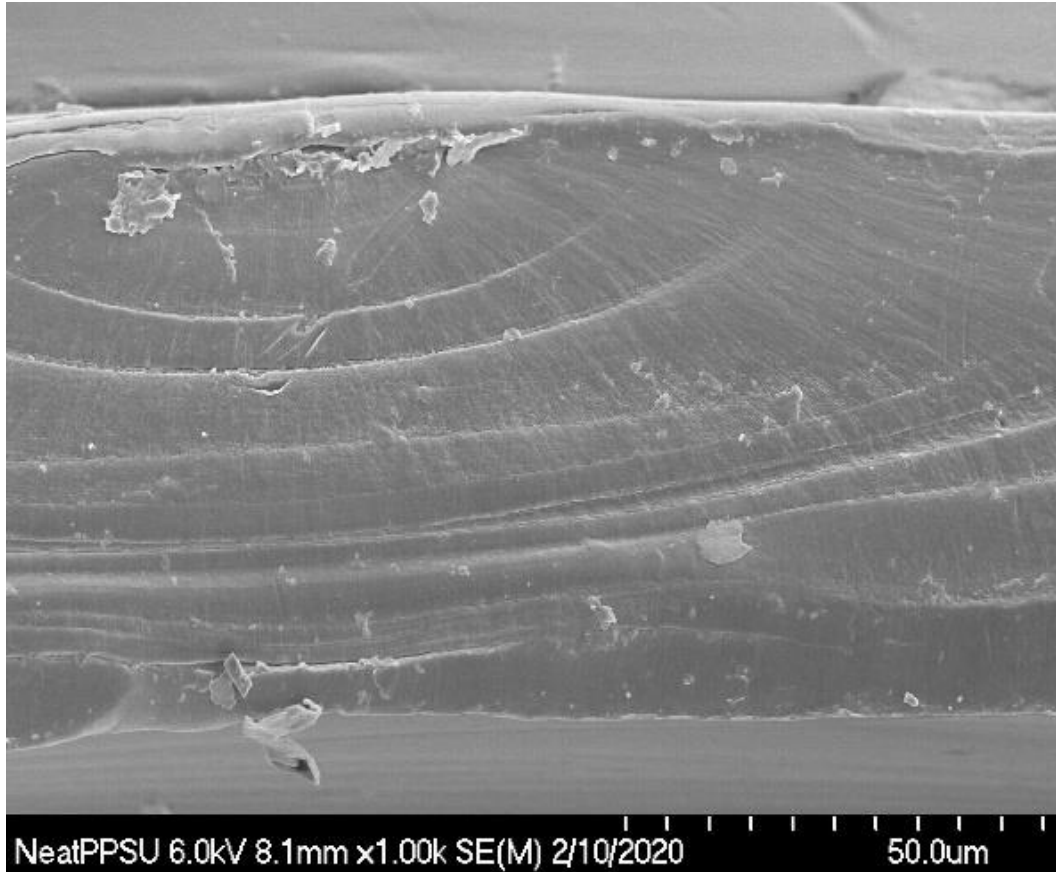
Rheological effects of modified polymer pellets



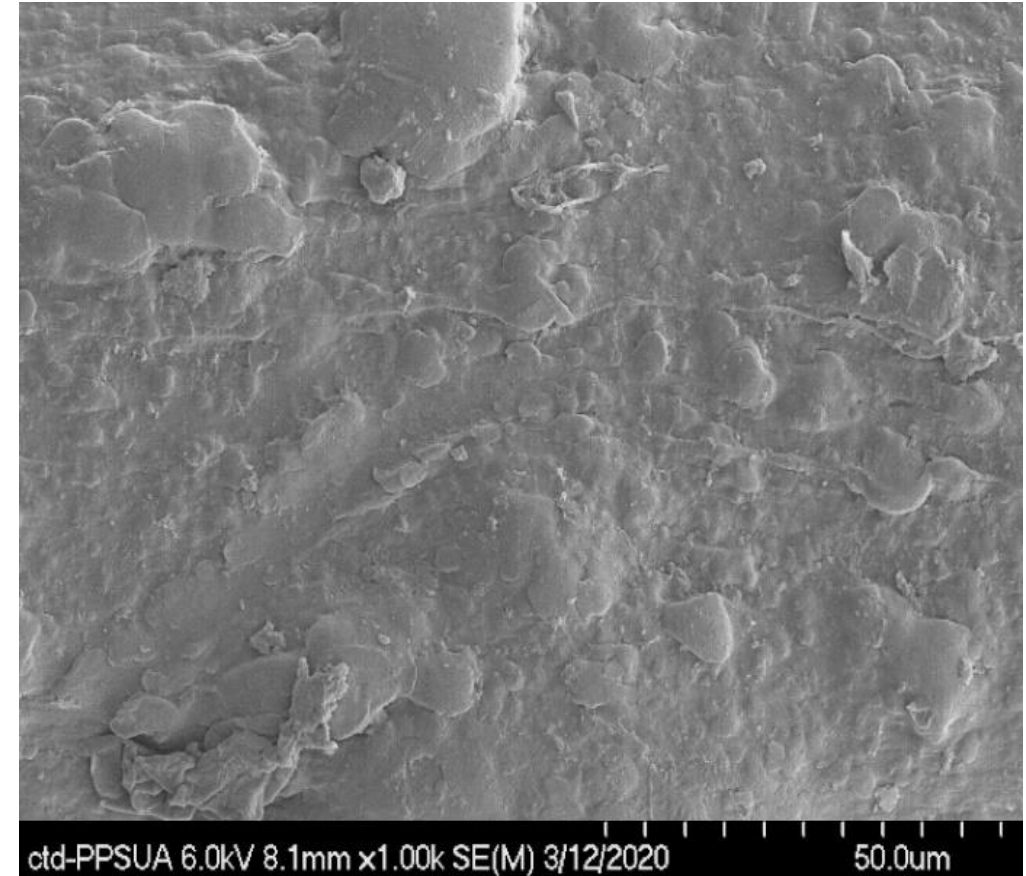
- Decreased low viscosity temperature
- Modification possibly created more “slip”
- Better thermal transfer (pre-compounded)



Cross-section of extruded PPSU and PPSU-hBN composite films

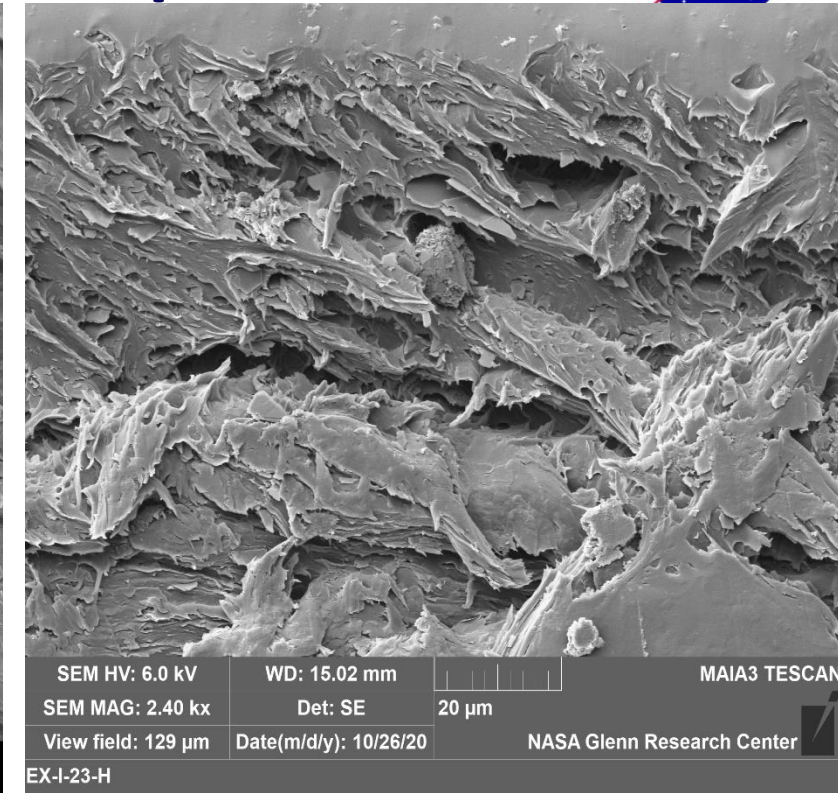
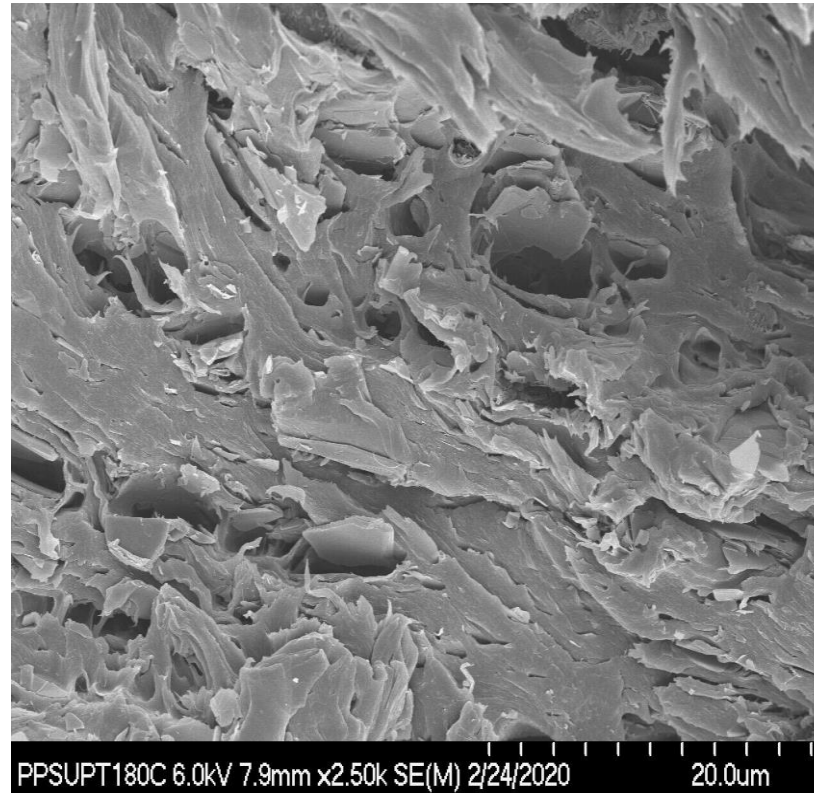
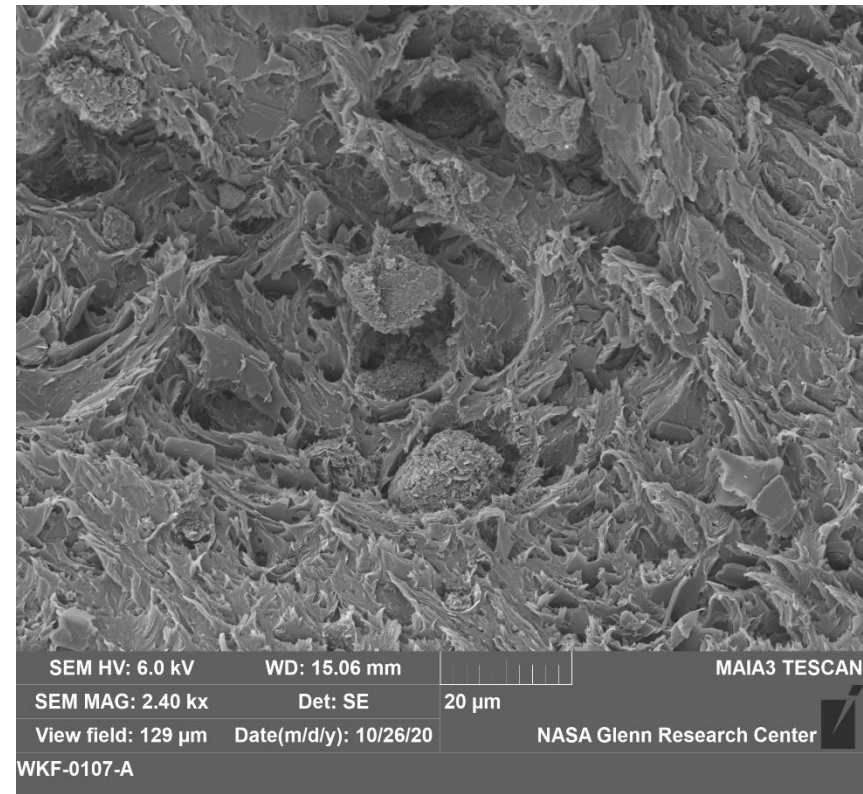


Virgin PPSU
DS: 41.7 ± 7.7 kV/mm



Modified PPSU
DS: 40.2 ± 2.2 kV/mm

Cross-section of extruded PPSU and PPSU-hBN composite films



PPSU A

8.8 wt% hBN

DS: 38.3 ± 4.7 kV/mm

PPSU B

~7.0 wt% hBN

DS: 44.7 ± 6.6 kV/mm

PPSU C

6.1 wt% hBN

DS: 47.4 ± 7.9 kV/mm

PPSU A: Polyphenylsulfone + micronized + nano hBN;
PPSU C: Modified polyphenylsulfone + micronized hBN

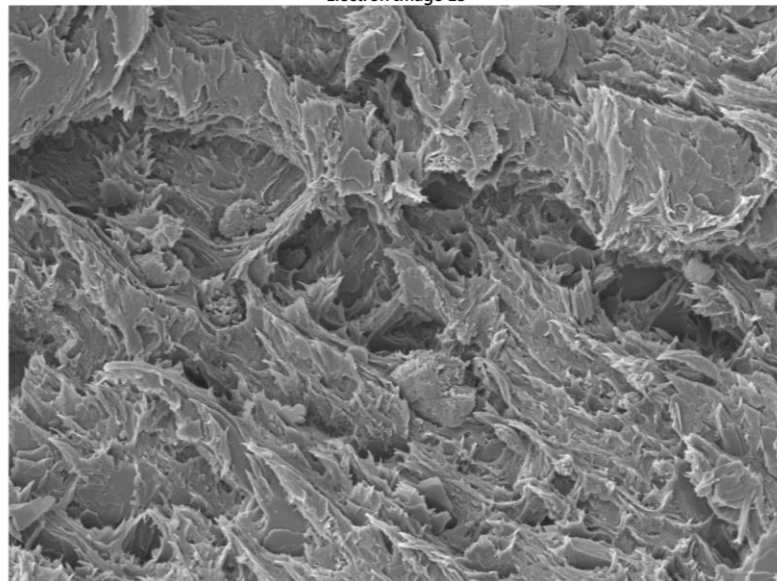
PPSU B: Polyphenylsulfone + micronized hBN;



PPSU A

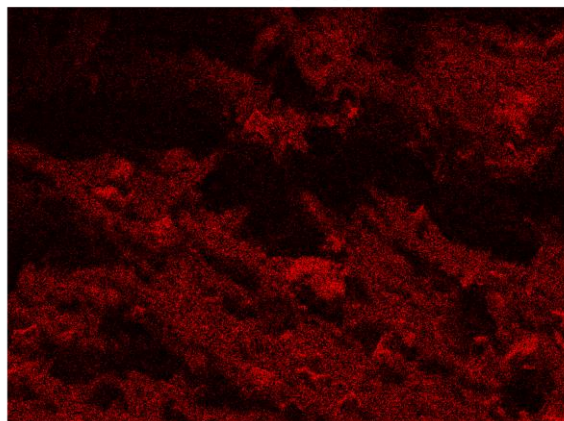
PPSU 8.8 wt% micro-/nano-hBN blend

Electron Image 13



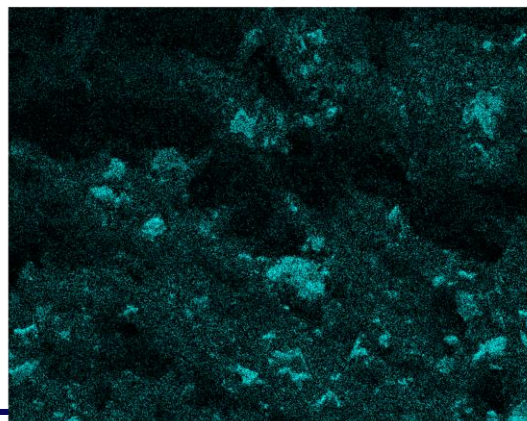
100µm

B K series



100µm

N K series

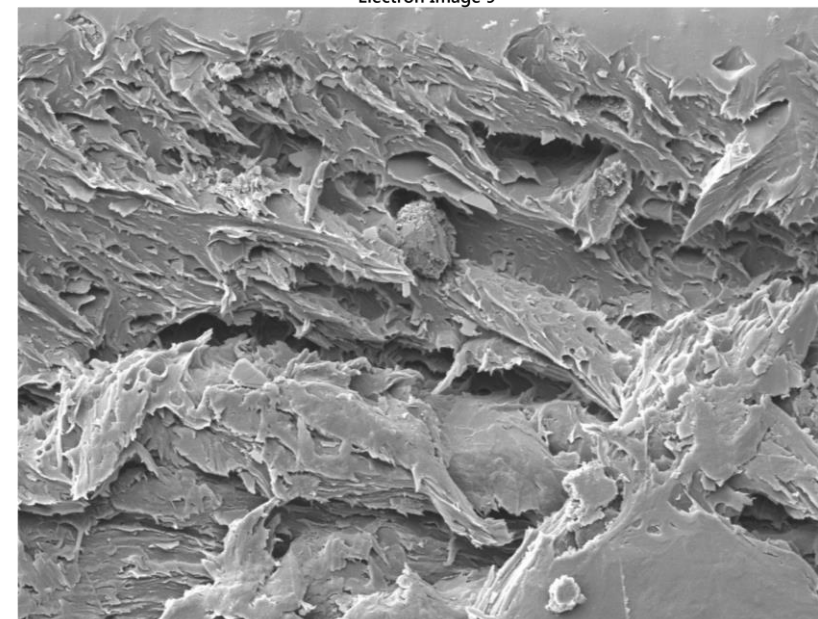


100µm

PPSU C

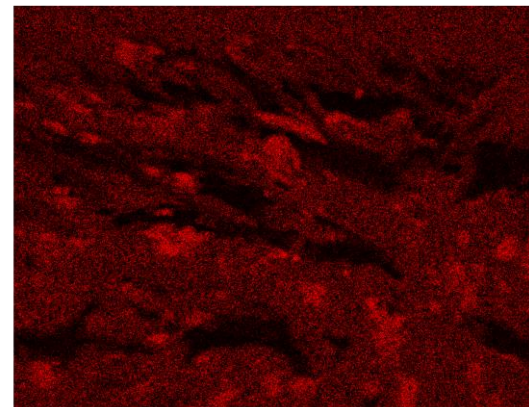
Modified PPSU 6.1 wt% micro-hBN

Electron Image 9



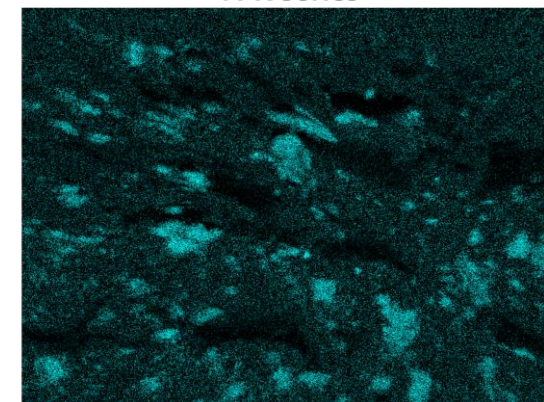
100µm

B K series



100µm

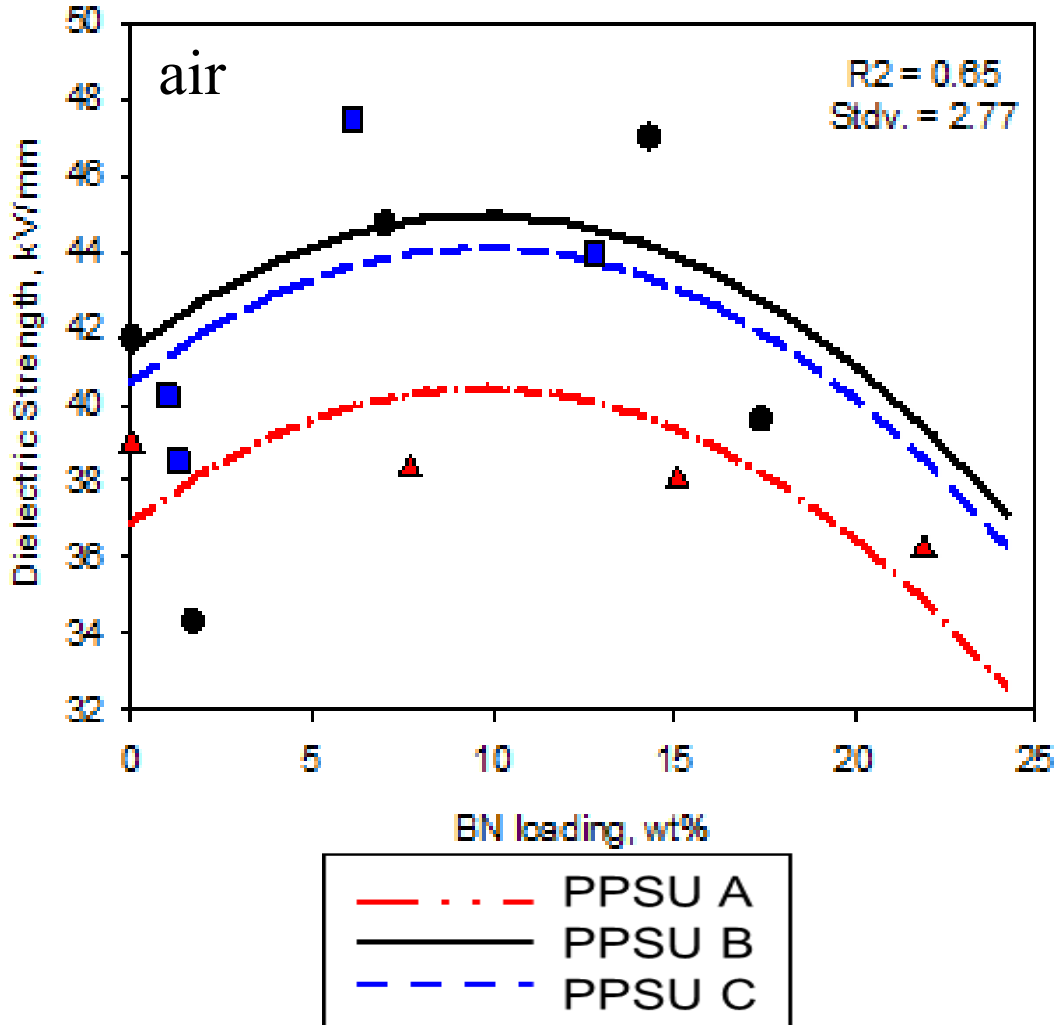
N K series



100µm



Dielectric Breakdown



PPSU A: Polyphenylsulfone + micronized + nano hBN

PPSU B: Polyphenylsulfone + micronized hBN

PPSU C: Modified polyphenylsulfone + micronized hBN

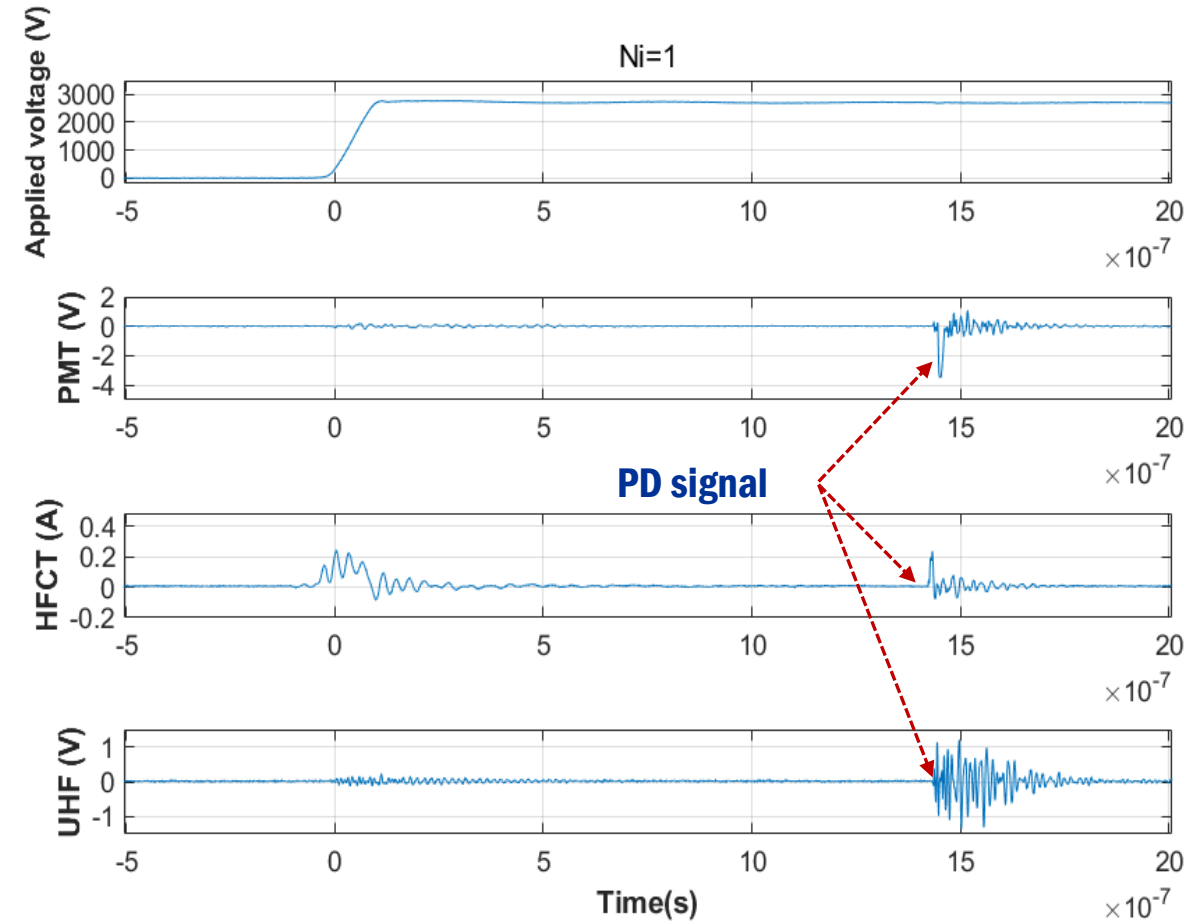
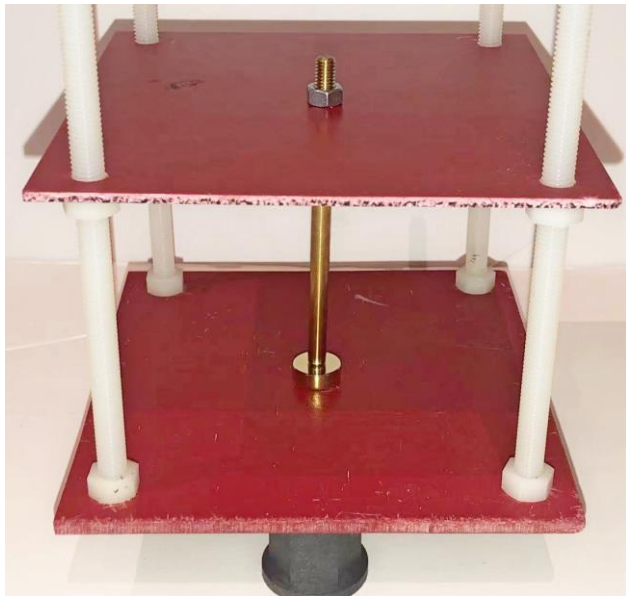
Enhanced dielectric strength at low filler loadings often attributed to creation of shallow traps¹

¹Saleem, M.Z.; Akbar, M. Review of the Performance of High-Voltage Composite Insulators. *Polymers* **2022**, *14*, 431. <https://doi.org/10.3390/polym14030431>

Repetitive Pulse Partial Discharge Tests

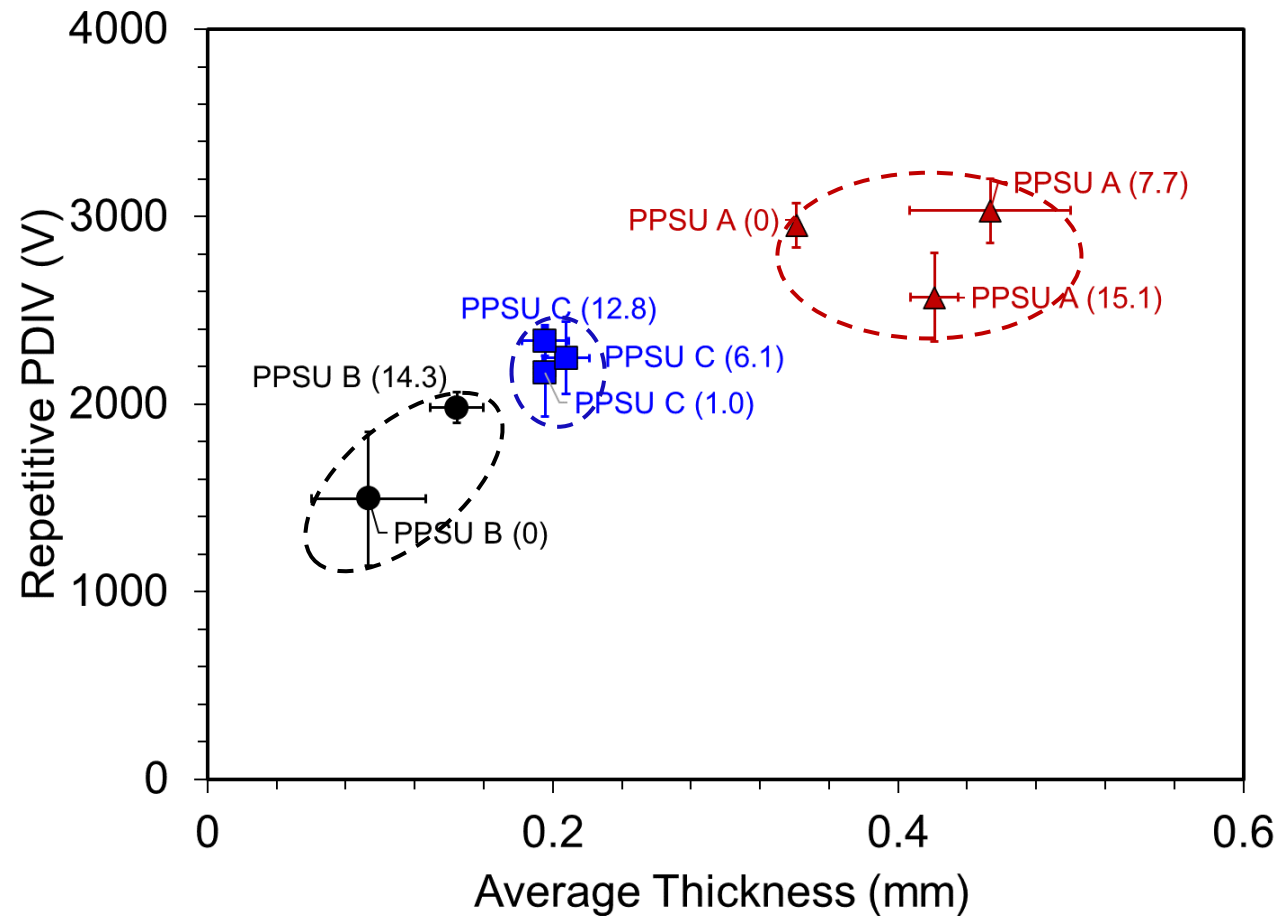
The electrode system utilized is rod-to-plate, both with rounded edges

- Rod electrode: $D=6$ mm, 1 mm rounded edge
- Plate electrode: $D=16$ mm, 1 mm rounded edge
- Tests conducted under ambient room pressure
- 10 kHz, $D=0.5$, $5\ \Omega$ gate resistance (55 ns rise time at 1 kV)
- Antenna: HFCT, PMT, UHF
- 10 pulses at each test repetition





Repetitive Surface Partial Discharge



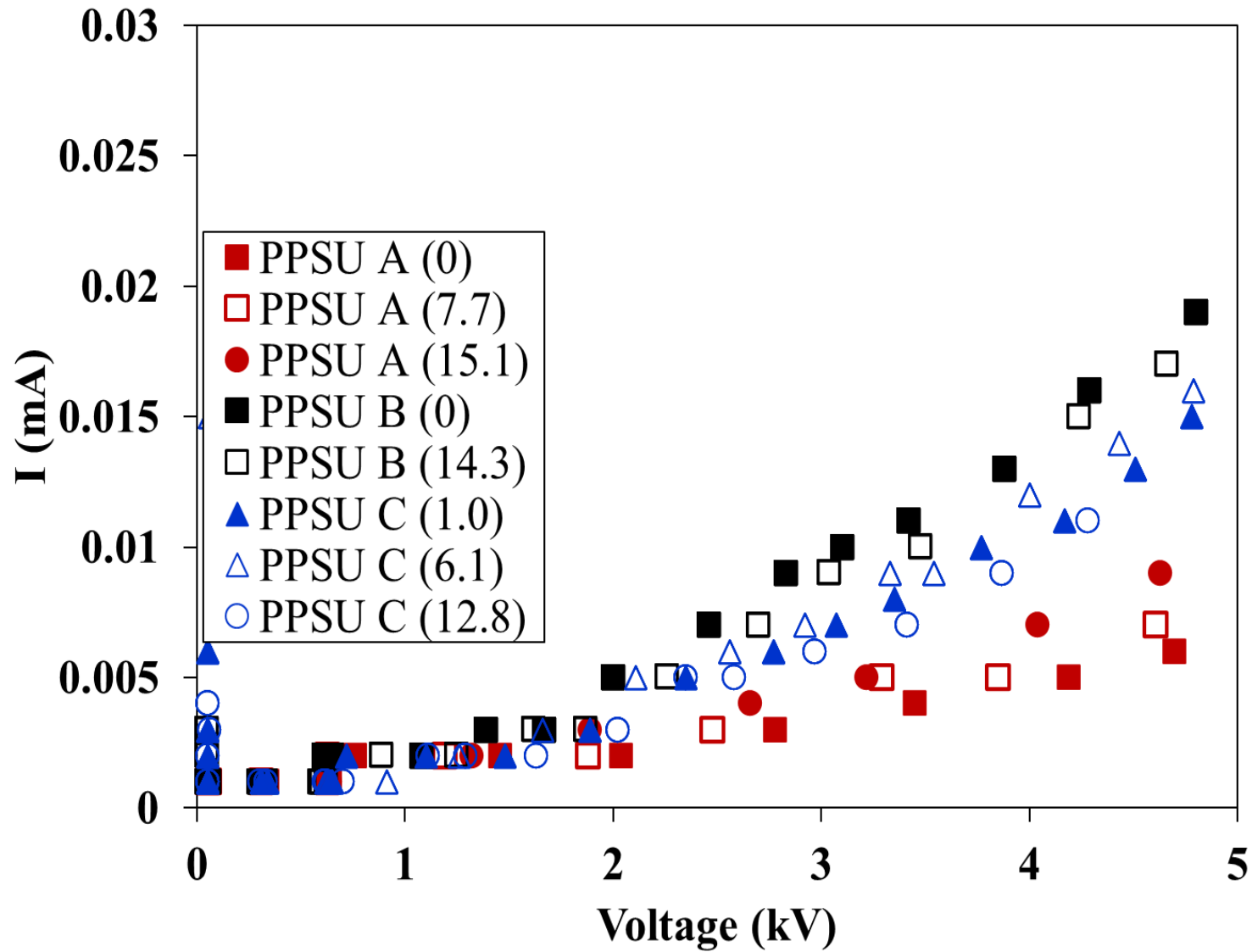
PPSU A: Polyphenylsulfone + micronized + nano hBN

PPSU B: Polyphenylsulfone + micronized hBN

PPSU C: Modified polyphenylsulfone + micronized hBN

- PPSU A only sample with lower RPDIV at highest filler loading
- Filler loading doesn't appear to affect RPDIV with only micronized BN
- Nano and modification demonstrated more impact on RPDIV

Current vs Voltage in PPSU-hBN Composite Films



	Film thickness (mm)
PPSU A	0.30 - 0.48
PPSU B	0.07 - 0.26
PPSU C	0.15 - 0.26



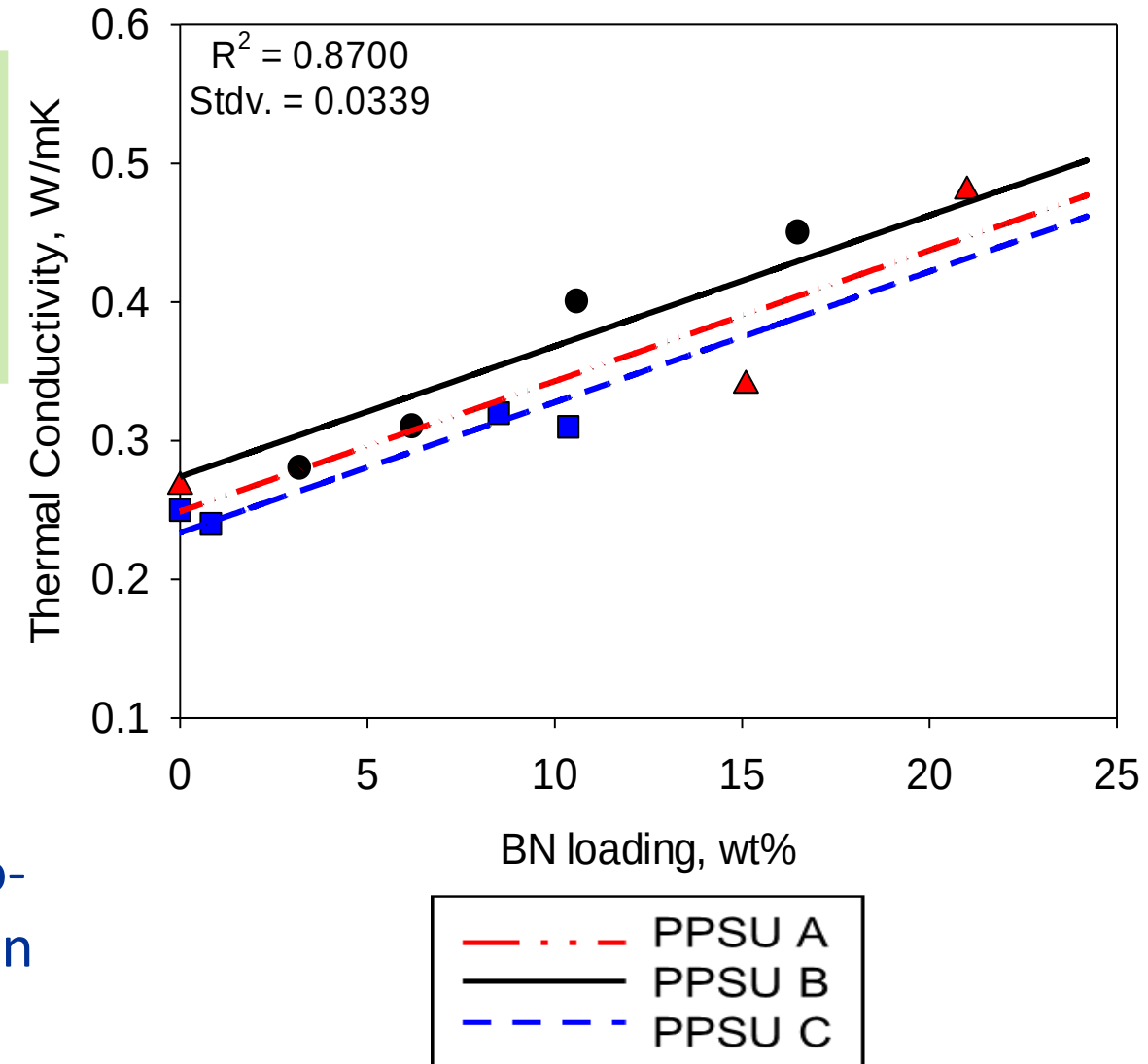
Thermal Conductivity of Extruded PPSU-hBN Films

PPSU A: Polyphenylsulfone + micronized + nano hBN

PPSU B: Polyphenylsulfone + micronized hBN

PPSU C: Modified polyphenylsulfone + micronized hBN

- Uncoated PPSU with micronized hBN demonstrated strongest increase in TC
- Modified PPSU possessed lowest TC values
- Better particle distribution and lack of particle-to-particle contact may have produced more phonon scattering in thin films





Conclusions

- Modification to the raw polymer pellet surface
 - Decreased viscosity and torque
 - Enhanced dielectric strength at lower filler loadings
 - Altered the appearance of cavity sizes in the microstructure
 - Did not exhibit sharp increase in thermal conductivity compared to other formulations
- Intentional mixing strategy should be implemented for processing composite insulation, while also taking into consideration filler geometry, size, and filler concentration.
- Future work includes extruding PPSU with additional novel geometries of boron nitride and more thorough study into dielectric analysis of PPSU-hBN thin films



Acknowledgement

- Funding Support: NASA Advanced Air Transport Technologies Project Aeronautics Research Mission Directorate
- Repetitive pulse partial discharge measurements: Dr. Jin Wang's Research Group (Center for High Performance Power Electronics at The Ohio State University, Columbus, Ohio, USA)
- SEM and Energy dispersive spectrometry: Dr. Wayne Jennings (HX5 LLC, Cleveland, Ohio, USA)
- Linda McCorkle: Rheology and SEM (University Space Research Association, Cleveland, Ohio, USA)



Thank you for listening!