FABRICATION OF EXTRUDED POLYPHENYLSULFONE – BORON NITRIDE COMPOSITE TAPES

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The Society for the Advancement of Material and Process Engineering

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THERMOPLASTICS COMPOSITES SESSION

FABRICATION OF EXTRUDED POLYPHENYLSULFONE – BORON NITRIDE COMPOSITE TAPES

Welcome

Tiffany Williams

- Researcher in Materials Chemistry and Physics Branch at NASA Glenn
- Background in processing polymer and polymer matrix composites
- Develops next generation polymer matrix composites for aeronautics and space
- Research interests: lightweight composites, multi-functional materials, textiles, nanomaterials, and bio-inspired materials

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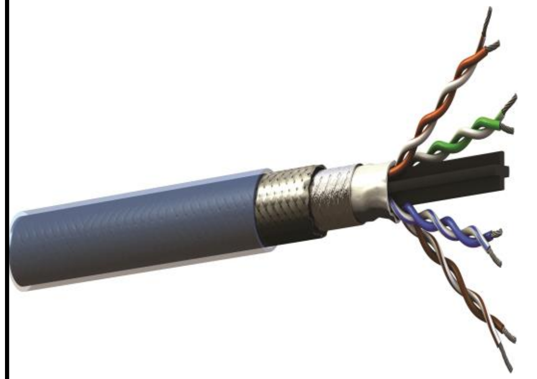
Background

- **Lifetime of electric motors will depend on the performance and durability of the electrical insulation**
- **<u>System need</u>**
  - ➢ Better thermal management for MW class, high power density (>13 kW/kg) electric machines
  - ➢ State-of-the-art insulation will rapidly degrade in the electric motor
    - Electrical stresses (higher operating voltages and frequencies, partial discharge)
    - Thermal stresses (higher operating temperatures >200 °C)
    - Environmental stresses (altitude, humidity)
  - ➢ **<u>New insulation materials needed</u>**
    1. Copper wire
    2. Slot liner
    3. Potting materials
  - Thermally conductive, composite insulation necessary to optimize engine performance in electric/ hybrid electric motors
  - Thermal conductivity of most electrical insulators: ~0.1 – 0.2 W/mK
  - Goal: ~1 W/mK thermal conductivity

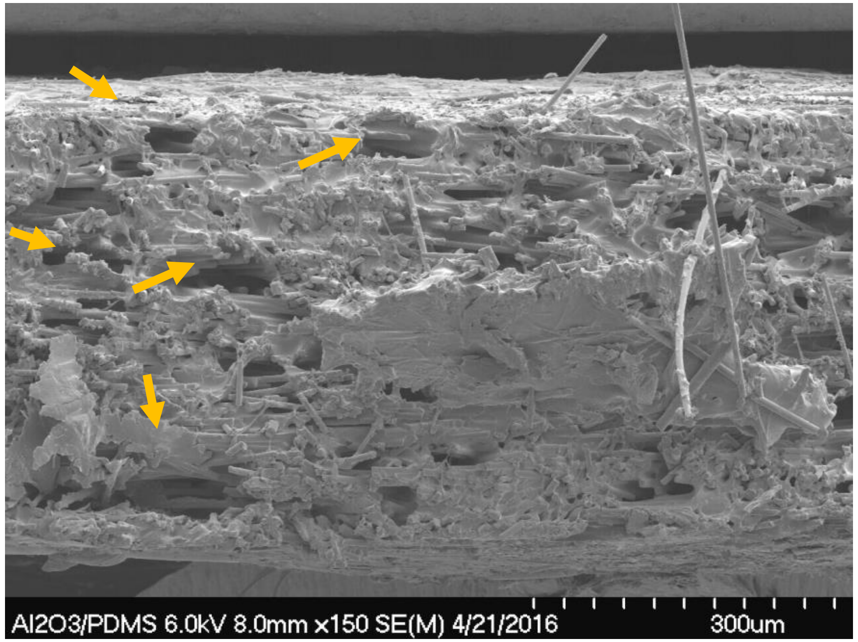


Lightweight power transmission system

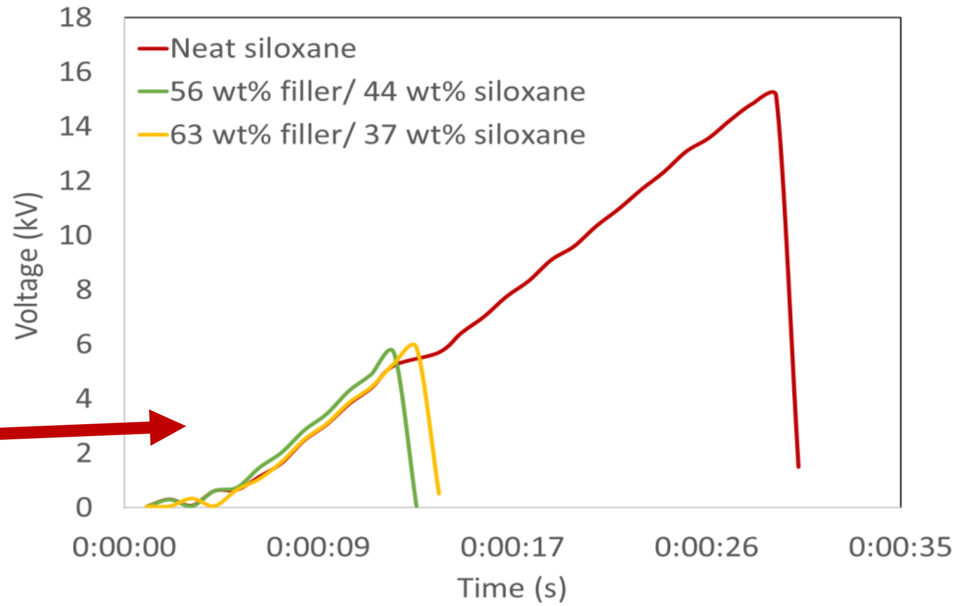
Thermally Conductive Composite Electrical Insulation

- **Common approach →** Incorporate conductive fillers to increase thermal conductivity of polymer insulation
- **Micro-structure of the composite insulation affects dielectric performance and thermal conductivity**
- **Adding dissimilar materials typically negatively impact insulation performance**
  - Lower dielectric strength
  - Higher chances of charge build up
  - Reduced flexibility
  - More interfacial polarization (Grains and grain boundaries)

Dry spots



61% decrease in dielectric breakdown voltage after fillers



Twin Screw Extrusion to Develop Thermally Conductive Composite Electrical Insulation

- **Advantages**
  - Improved polymer orientation
  - Better filler dispersion and distribution
  - Preferred filler directionality and alignment
  - Scalable
  - Tailorable processing
  - Solvent-free processing approach
  - Easy to incorporate fillers

Improves dielectric performance and thermal conductivity (the first three advantages)

- **Extruded composite insulation resulted in higher thermal conductivity and dielectric performance[1]**
  - ~14 – 19% increase in dielectric strength
  - 2 – 5x's increase in thermal conductivity

[1]Williams, T., Nguyen, B., Fuchs. W. *Polyphenylsulfone-hBN Composite Insulation.* Valencia, Spain : IEEE, 2020. IEEE 2020 International Conference on Dielectrics. pp. 541-545.

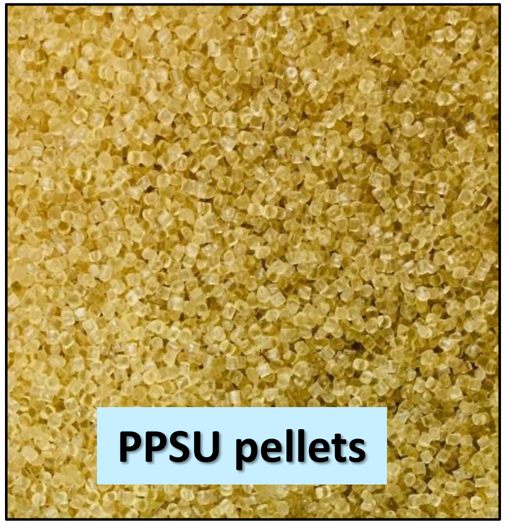
- **Objective: Discuss extrusion process and properties of composite insulation**

High temperature benchtop extruder

Extruded Thermally Conductive Composite Insulation

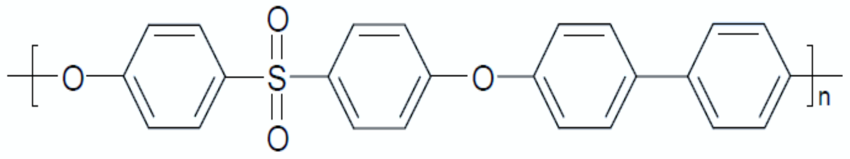
- **PPSU Characteristics**
  - High toughness and impact resistance
  - 230 °C T_g
  - Heat deflection temperature of ~207 °C
  - Inherent flame retardant
  - Chemical resistance
  - Low moisture absorption
  - Limited to 180 °C continuous operating temperature
  - Not UV stable
  - Avg. pellet size: 2 – 3 mm

- **Boron nitride (BN) powder**
  - Exceptionally high thermal conductivity
  - Electrically insulating
  - Radiation shielding
  - Mean particle size: 6-9 μm

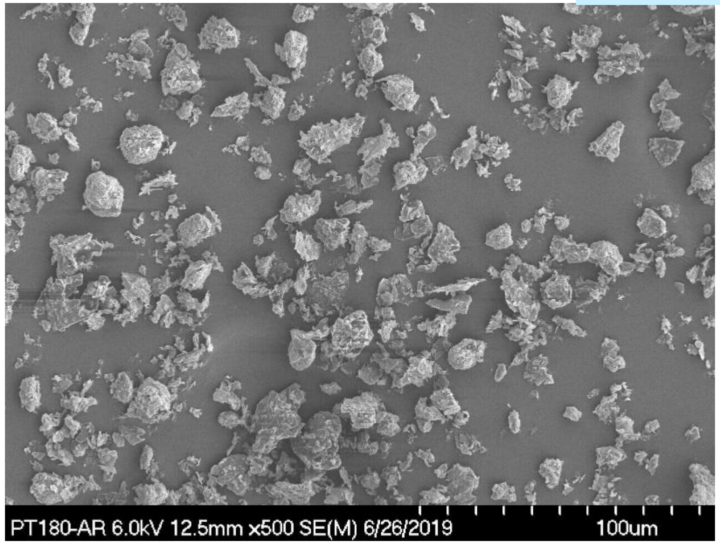


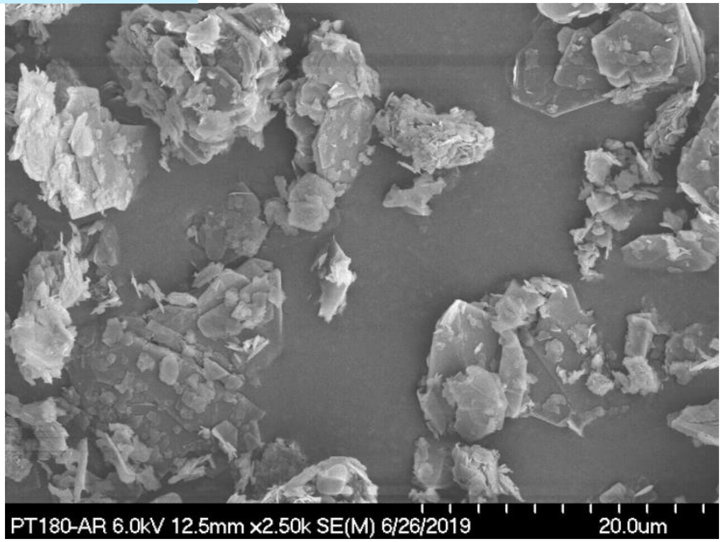
PPSU pellets

Polyphenylsulfone (PPSU)



micro-BN platelets

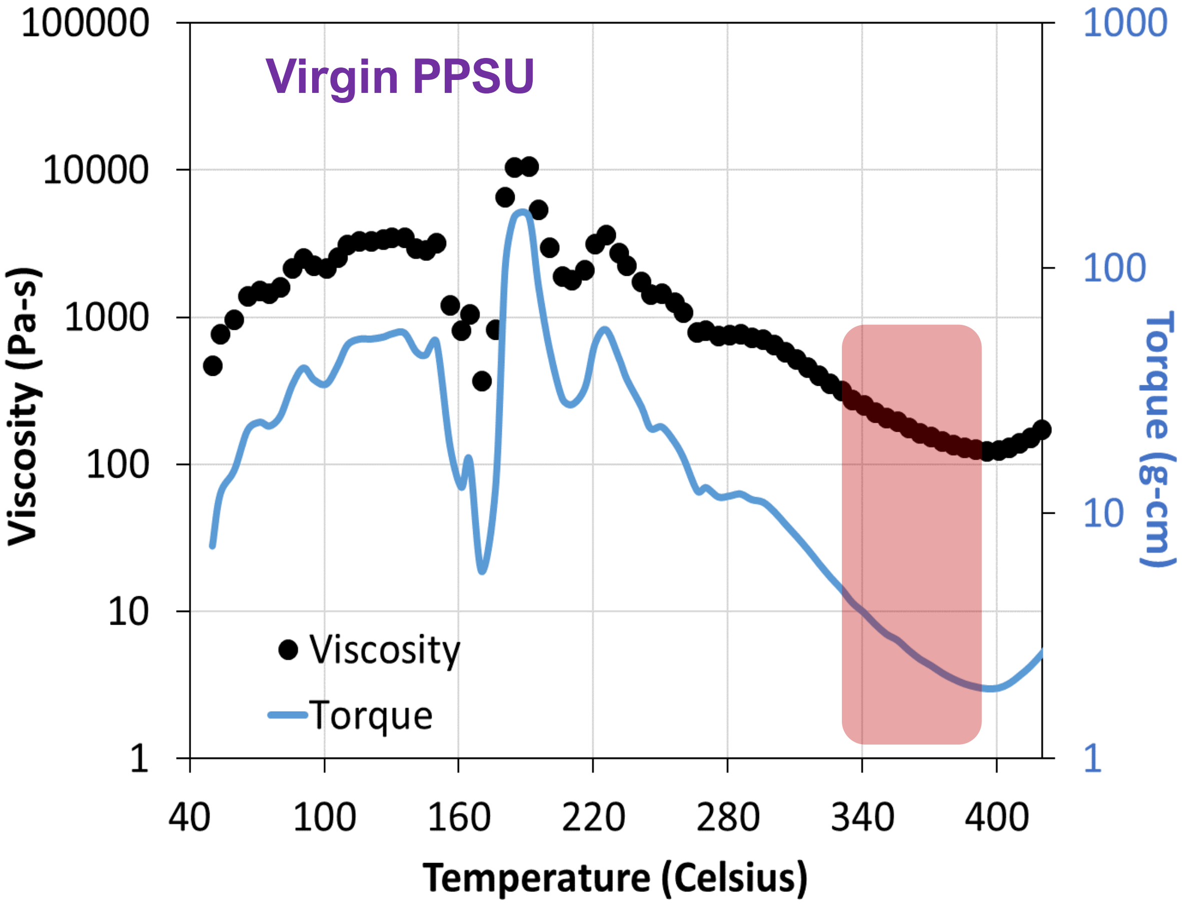




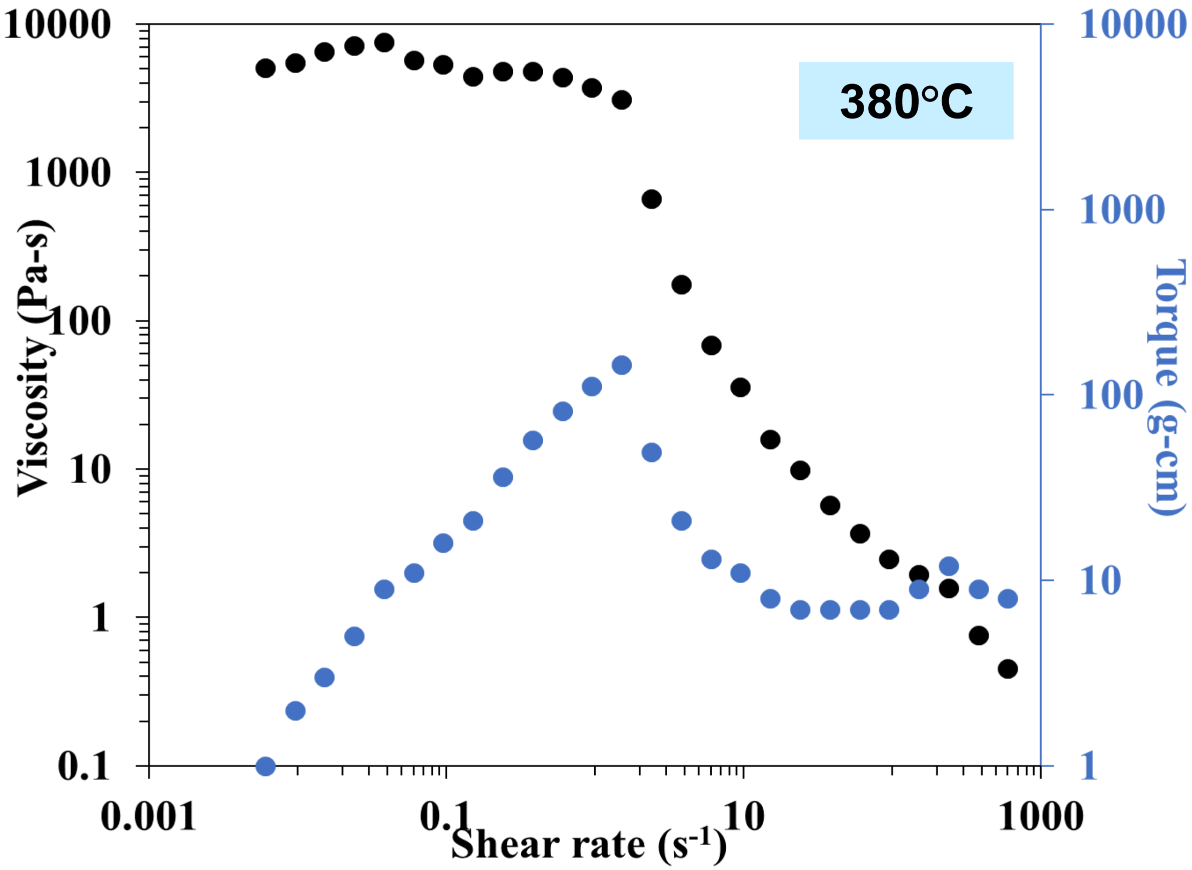
Literature on the dielectric properties of PPSU and their composites are limited.

Rheology Profile for Virgin PPSU

Vendor recommended temperature range for extrusion 338 – 388°C



hBN fillers will increase viscosity and torque



Transition from zero shear <1 s^{-1} to shear thinning >1 s^{-1}.

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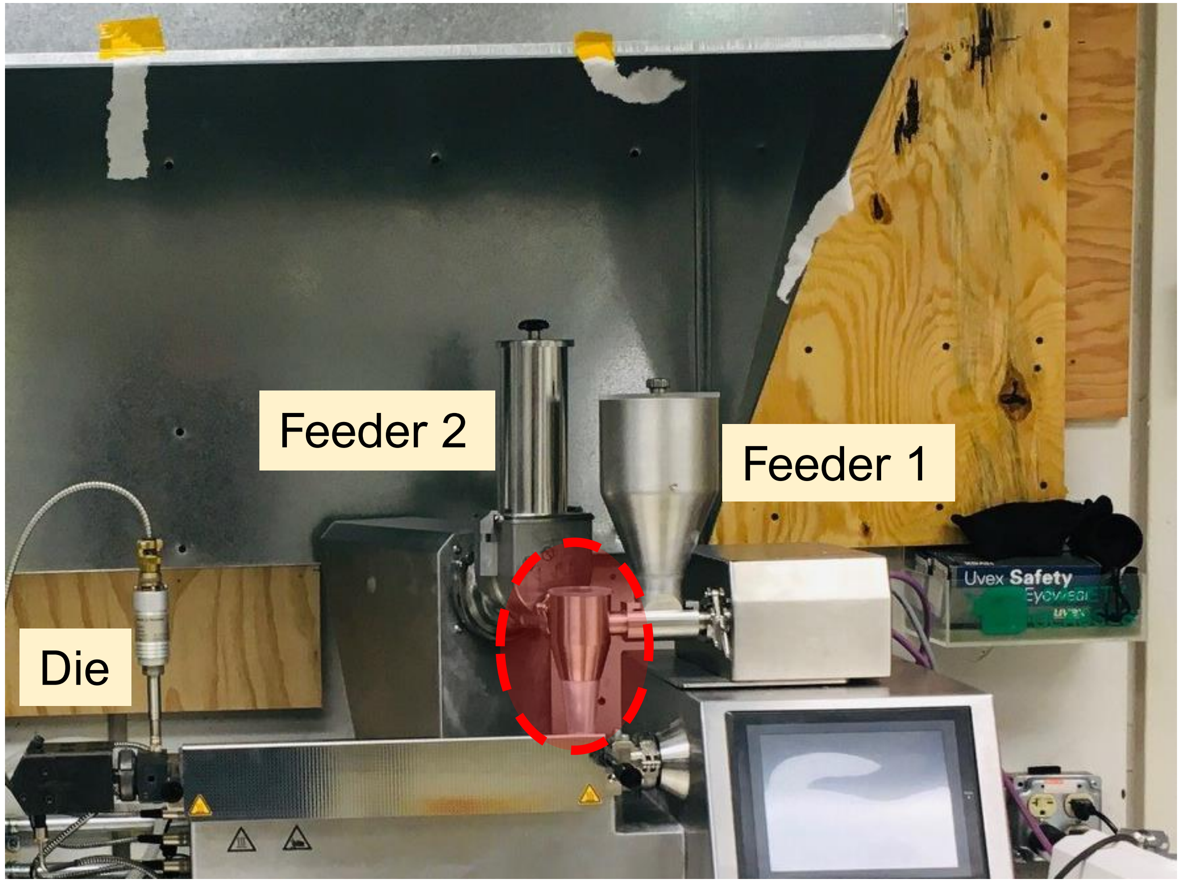
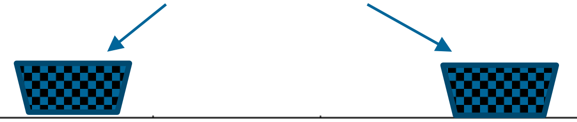


- PPSU pellets were pre-dried prior to extrusion
- Feed rates of polymer and hBN filler feeders pre-calibrated prior to extruding
- Fed into barrel in as-received forms
- Adjustable slit die ~0.1 mm
- Pellets and hBN platelets introduced at Zone 1
- **Hardness of polymer pellets affect feeding rate**
- *Virgin PPSU and PPSU-hBN composites extruded in continuous run*



Zone #	Die	8	7	6	5	4	3	2
Set (°C)	350	350	350	370	370	380	380	380
Actual (°C)	350	350	350	370	370	380	359	278

Co-rotating twin screw
Screw speed: ~ 80 rpm

Barrel zones: 7 x 5 L/D

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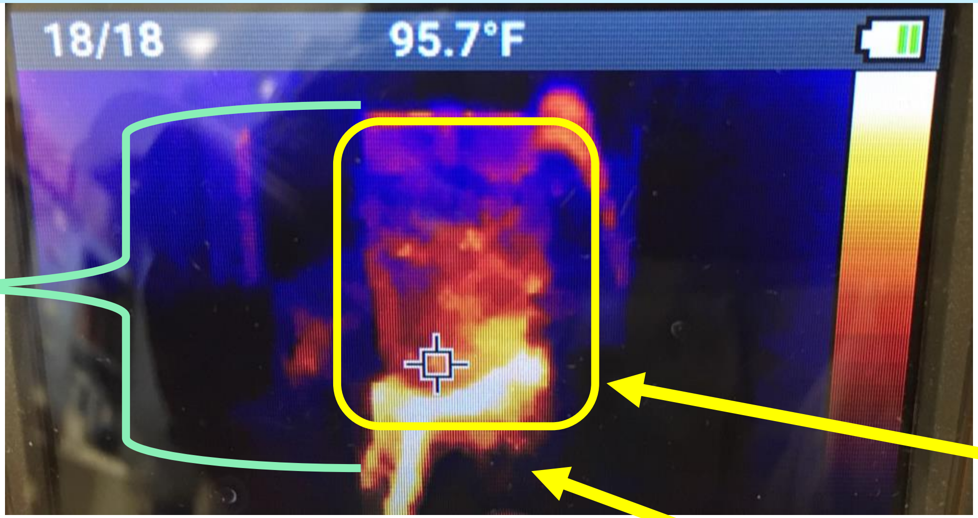
Infrared Thermal Image of Feeder Vessel



Pellet feeder vessel

Thermal profile of feeder container with heat tape secured with aluminum foil

Exposed area of wrapped heat tape at bottom of feeder

Heat tape on feeder vessel appeared to be effective with reducing hardness of PPSU pellets

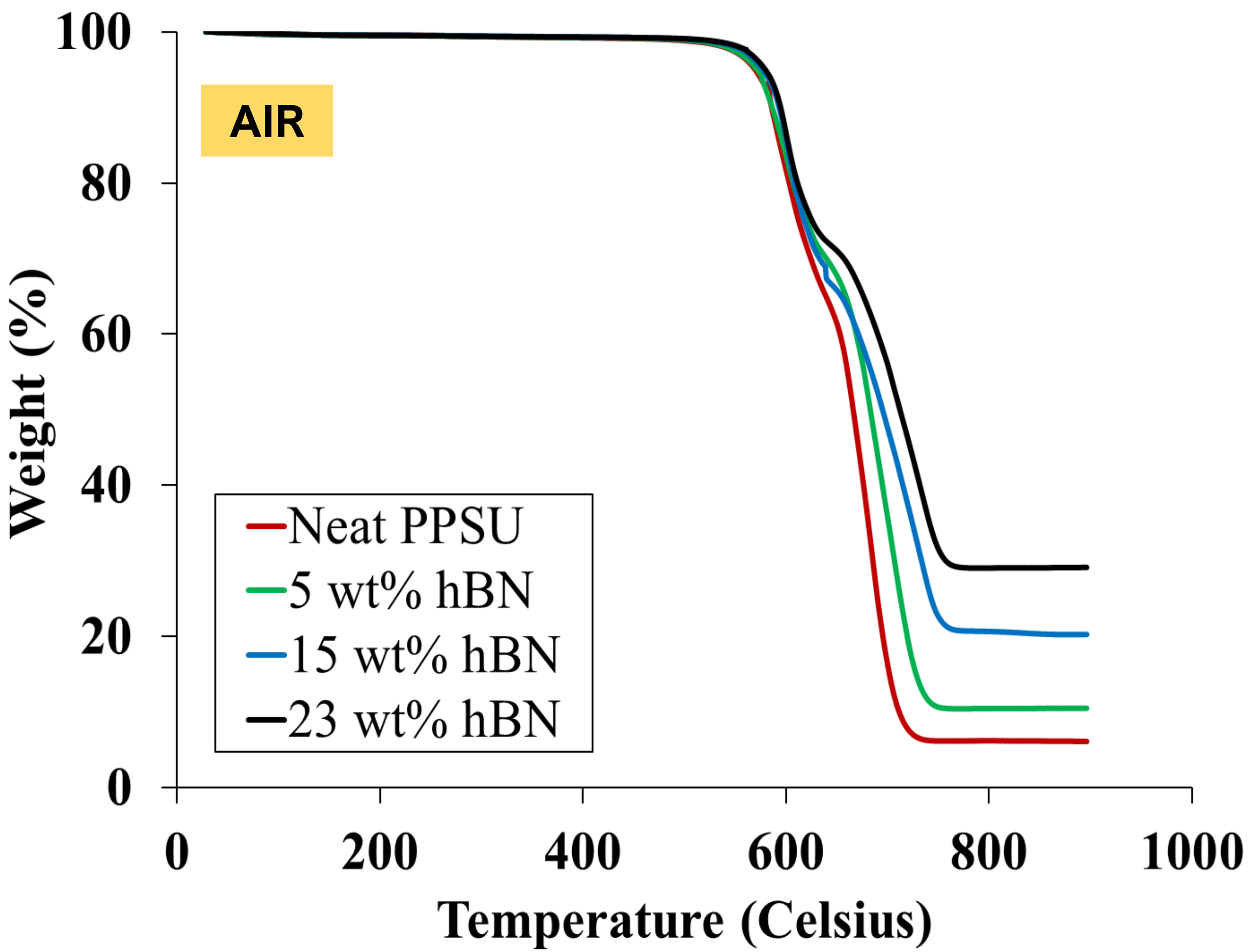
Pellets retained original shape after being dispensed.

PPSU-hBN Composite Tape Extrusion

Water-chilled rollers and air knife

Take up spool

Thermo-gravimetric Analysis (TGA)



- Used to confirm filler loading
- Evaluate hBN effect on decomposition

	T_{d1}	T_{d2}
Neat	543.2 ± 52.0	660.3 ± 3.5
~ 5 wt%	574.9 ± 4.8	662.6 ± 3.9
~ 15 wt%	579.7 ± 1.9	665.2 ± 7.1
~ 23 wt%	579.1 ± 2.9	687.0 ± 4.2

Thermal stability
Sulfonated groups < Main chain hydrocarbons

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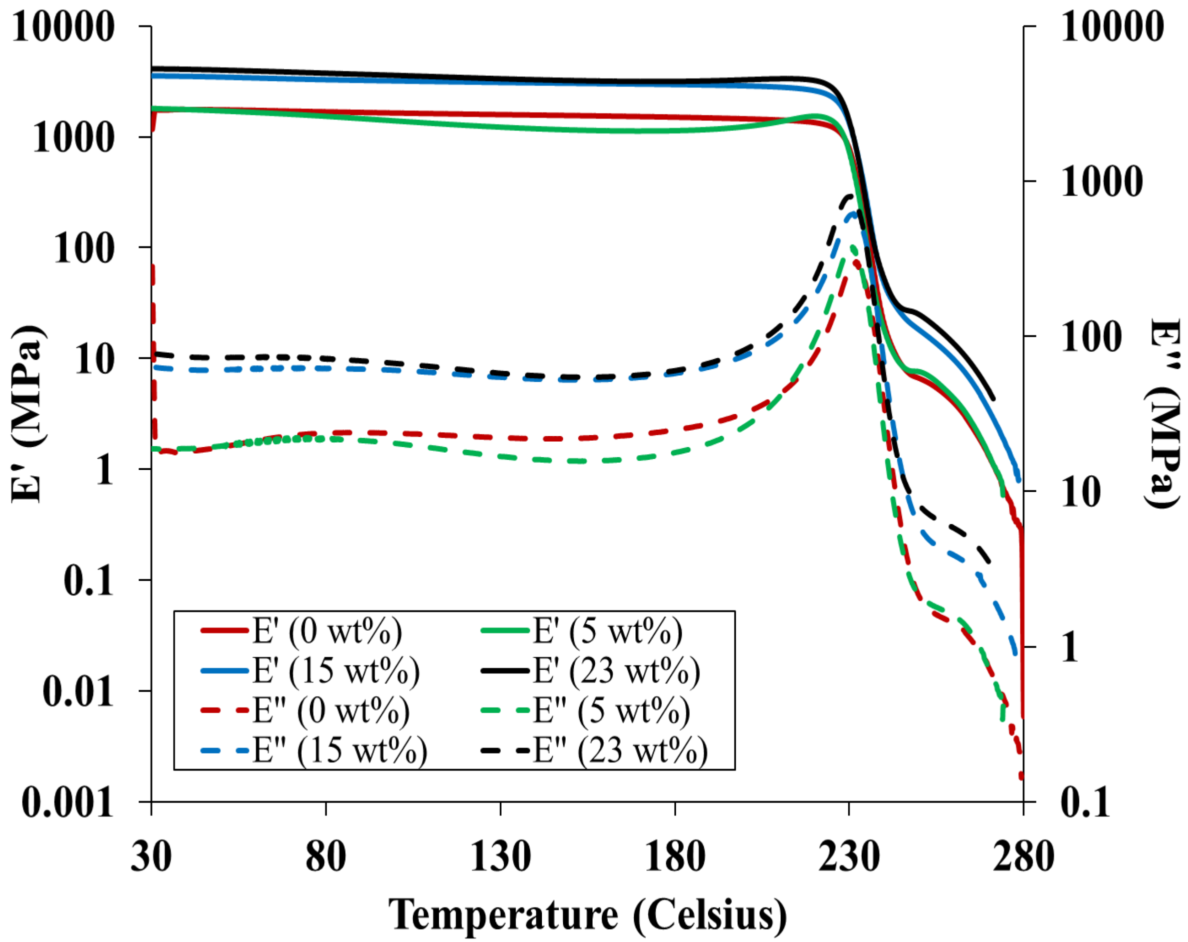
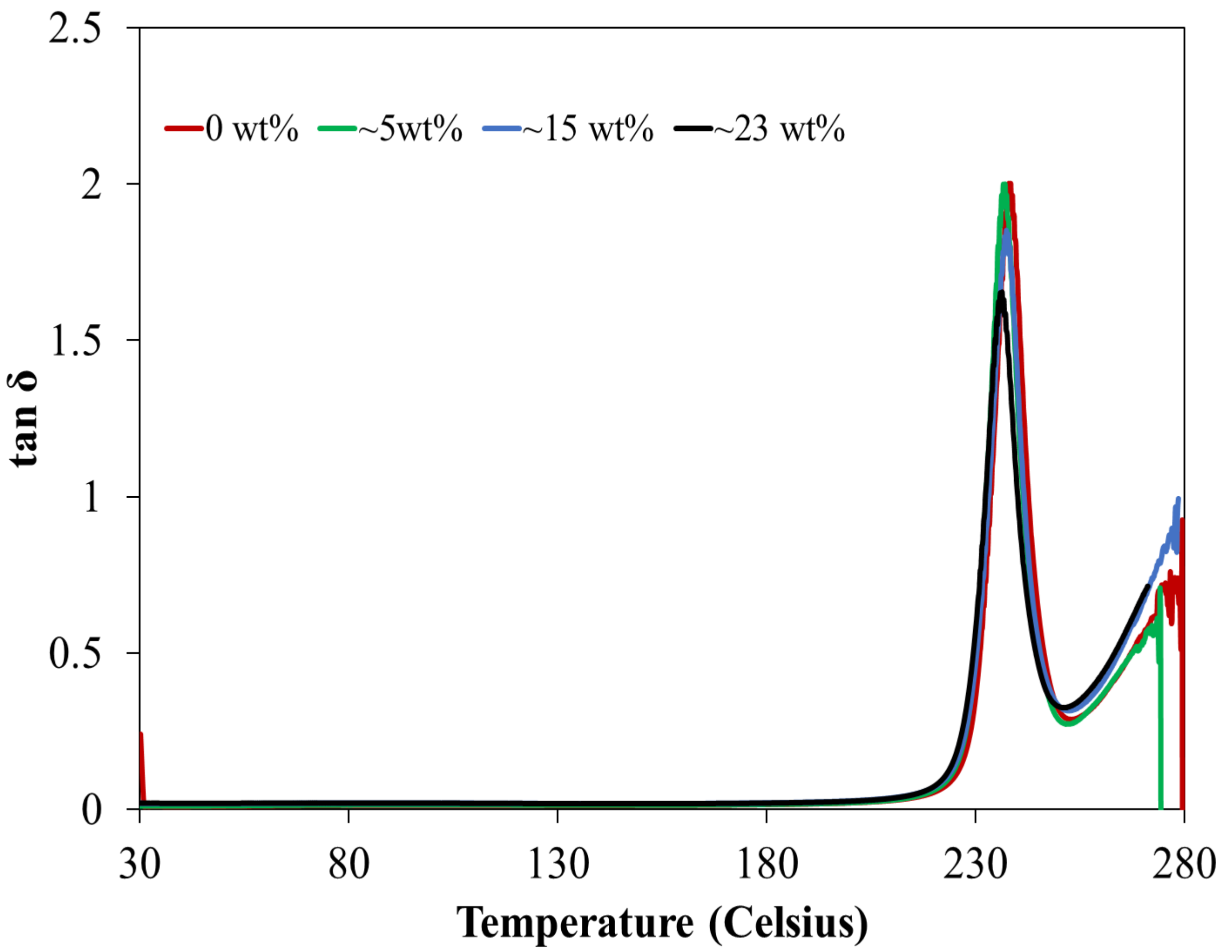
Dynamic Mechanical Analysis of PPSU-hBN

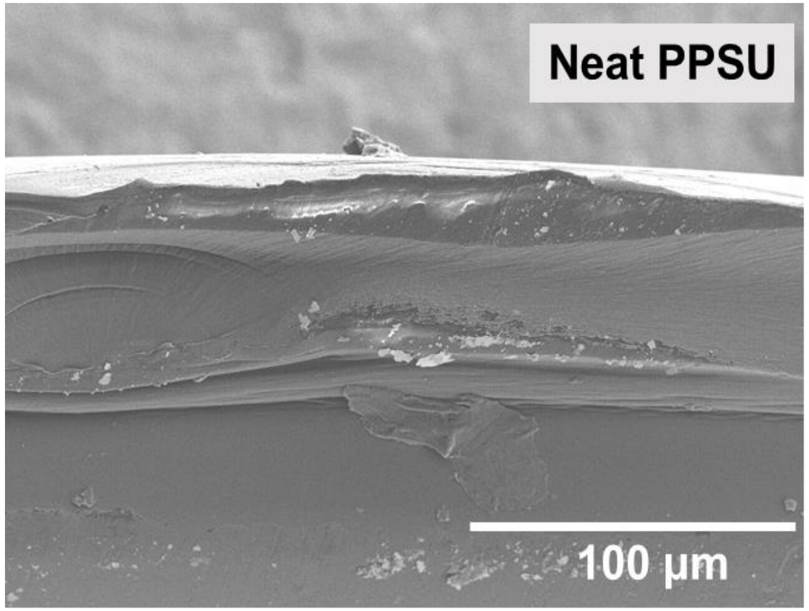


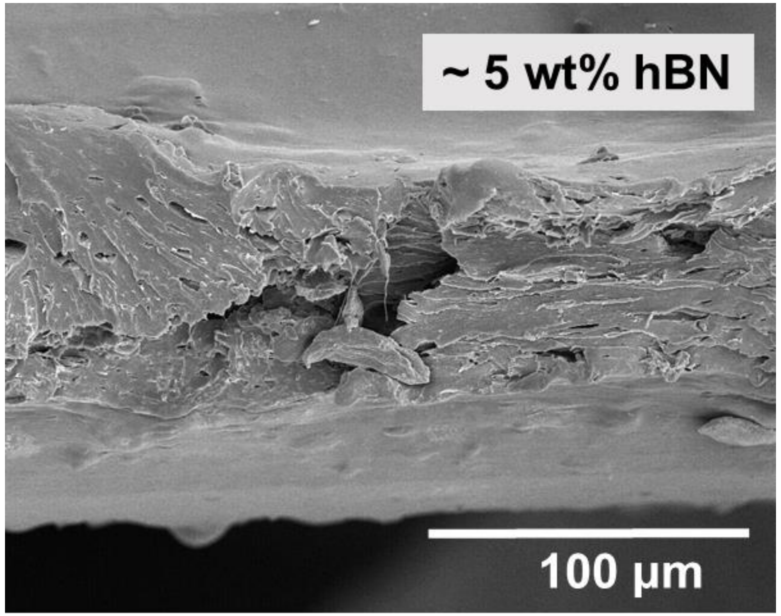
Higher loss modulus → more molecular friction → greater energy dissipation

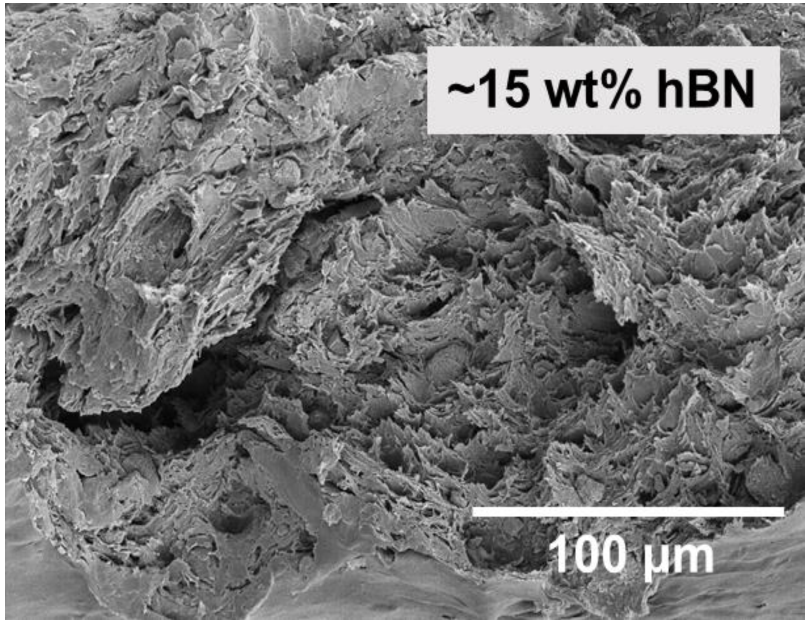


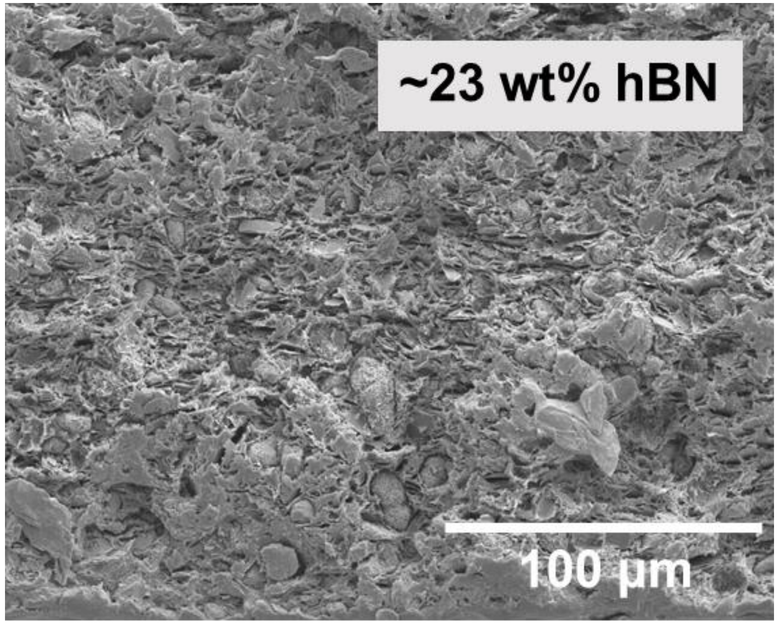
No significant change in T_g. Stiffer film most noticeable at highest hBN loading

Morphology of PPSU-hBN Composite Tapes









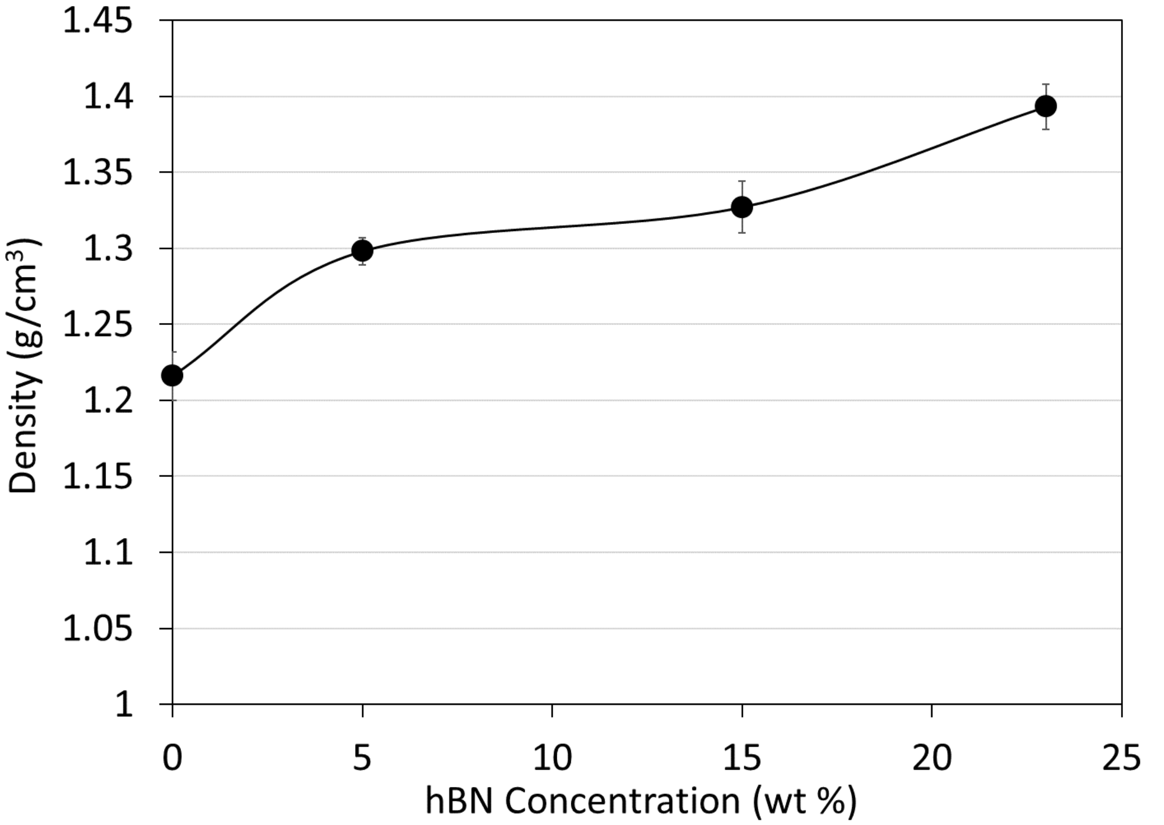
Geometry of gaps at particle-matrix interface show particle alignment along extrusion plane

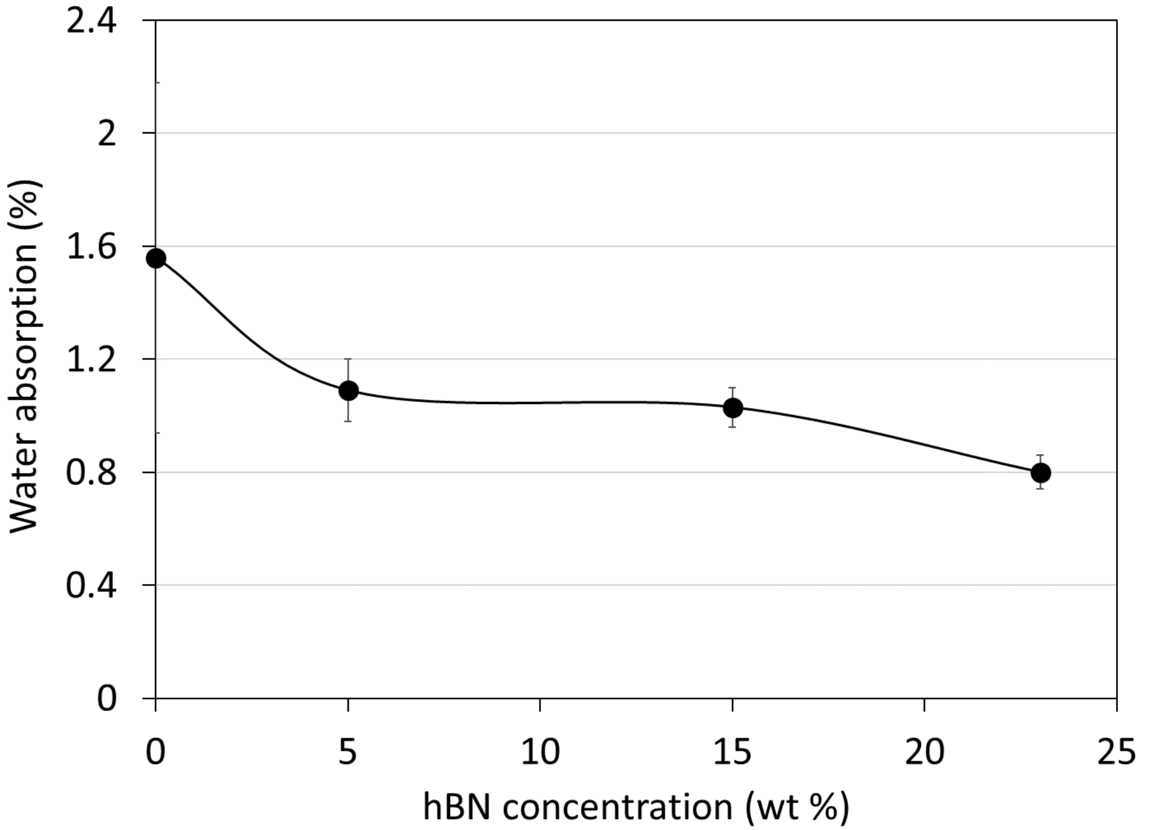
More roughness and appearance of agglomerates evident at higher hBN filler concentration

↓

Possibly caused by feeding method

Effect of hBN Concentration on Density and Water Absorption





~23 wt% hBN concentration corresponded to ~15% density increase

Water absorption decreased with increasing hBN content

Trade-off: Better thermal management and dielectric properties at the expense of more weight

Summary

- Up to 23 wt% hBN concentration achieved
- E’ and E” increased with increasing hBN concentration.
- ~1.7 GPa for neat PPSU and increased up to ~ 4.1 GPa. No change in T_g at higher filler loading.
- Lower moisture absorption and increase in density with increasing hBN

Future Work

- Optimize extrusion process: filler feeding location, screw design for optimal filler dispersion and distribution
- Perform more rheology measurements on PPSU-hBN to understand affect of hBN platelets and shearing on viscoelastic properties

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