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Mechanical and Microstructural characterization of Montmorillonite (MMT) Sodium Ion Conductors

University of Kentucky

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❑Motivation

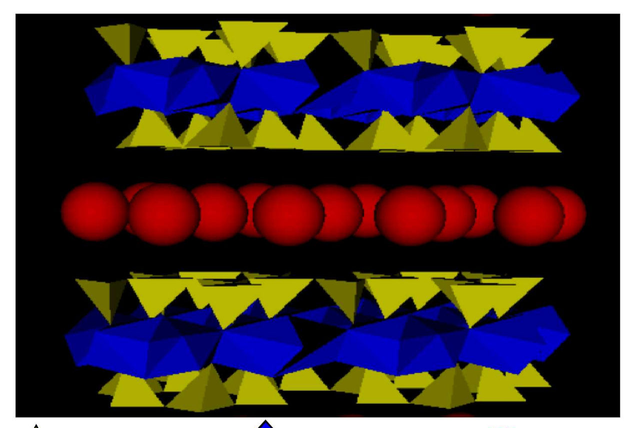
The DOE Office of Electricity views sodium batteries as a priority in pursuing a safe, resilient, and reliable grid. Improvements in solid-state electrolytes are key to realizing the potential of these large-scale batteries

❑Objective

- **Identify fundamental structure-processing-property relationships in montmorillonite sodium-ion conductors to inform design for use in sodium batteries**

❑ Montmorillonite Ion Conductors

- Clay sheets composed of one layer of AlO_6 octahedra between two layers of SiO_4 tetrahedra.
- Sheets are negatively charged due to substitutions and charged is balanced by dissolved cations
- 2D hydrated interlayers transport Na^+, similar to β"-Al_2O_3
- Inexpensive material, low-temp processing, and tunable properties



Pressed MMT Pellet

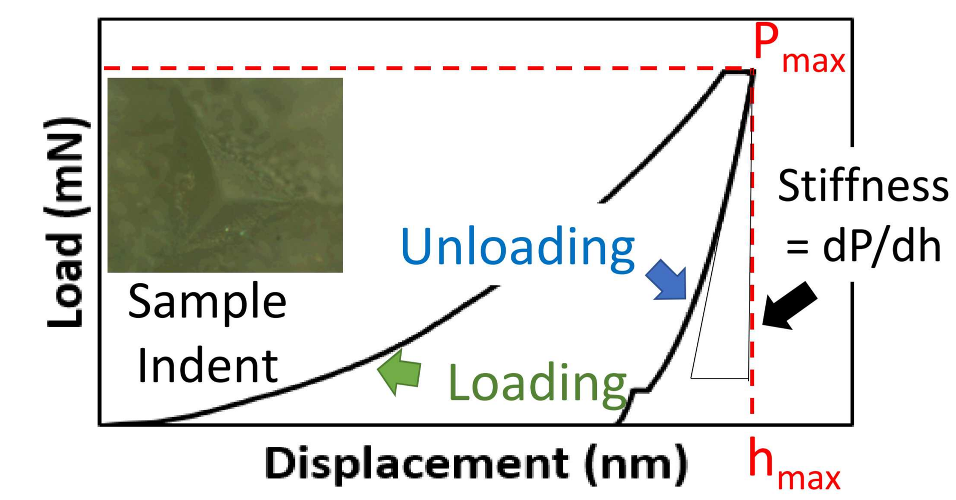
❑ Characterization Methodology

- **Nanoindentation** –small deformation to measure modulus and hardness by Oliver-Pharr Method

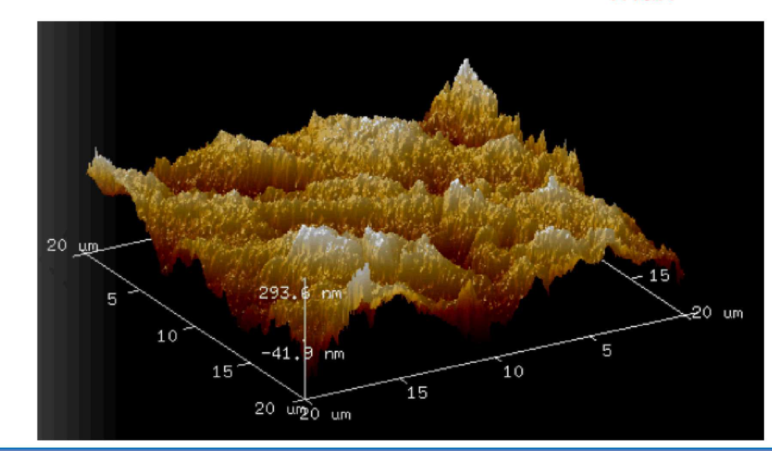
$$\frac{1}{E^*} = \frac{1-\nu^2}{E} + \frac{1-\nu'^2}{E'}$$

$$H = \frac{P_{max}}{24.5h_p^2}$$

Oliver-Pharr Equations

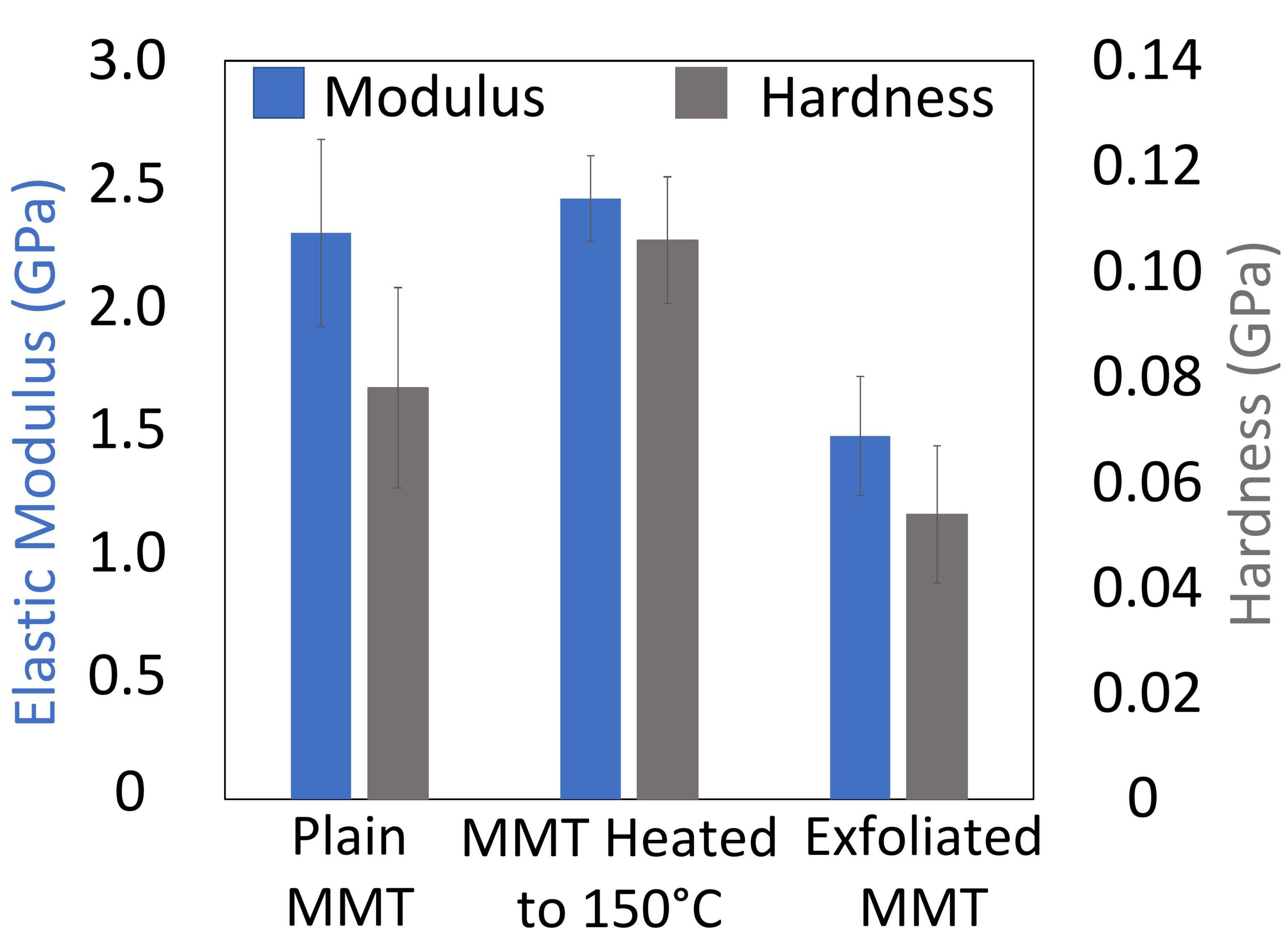


- **Atomic force microscopy** – topography and spatial mapping of elastic modulus



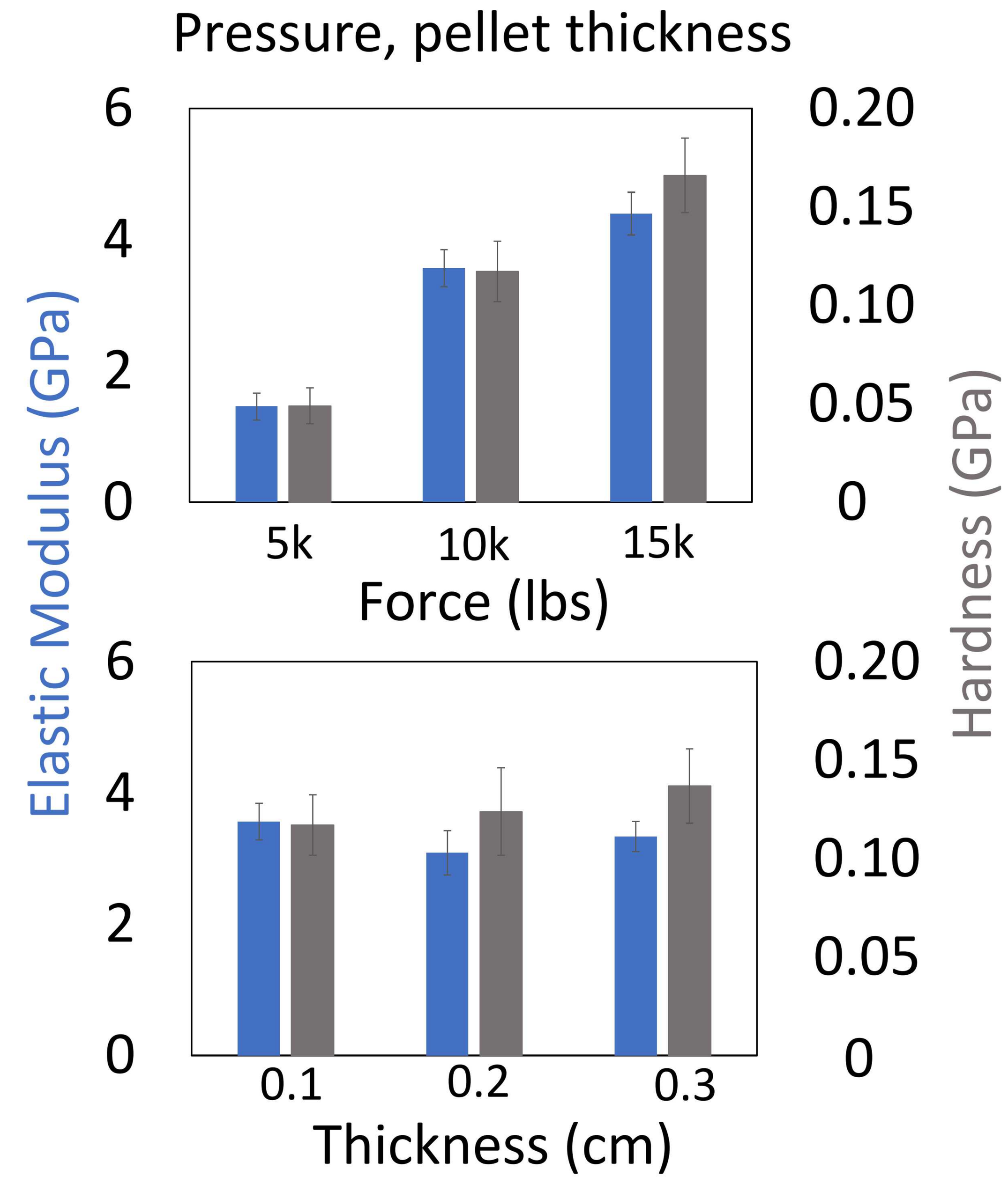
❑Mechanical properties of pellets can be controlled by:

- Montmorillonite (MMT) structure – water content, platelet orientation



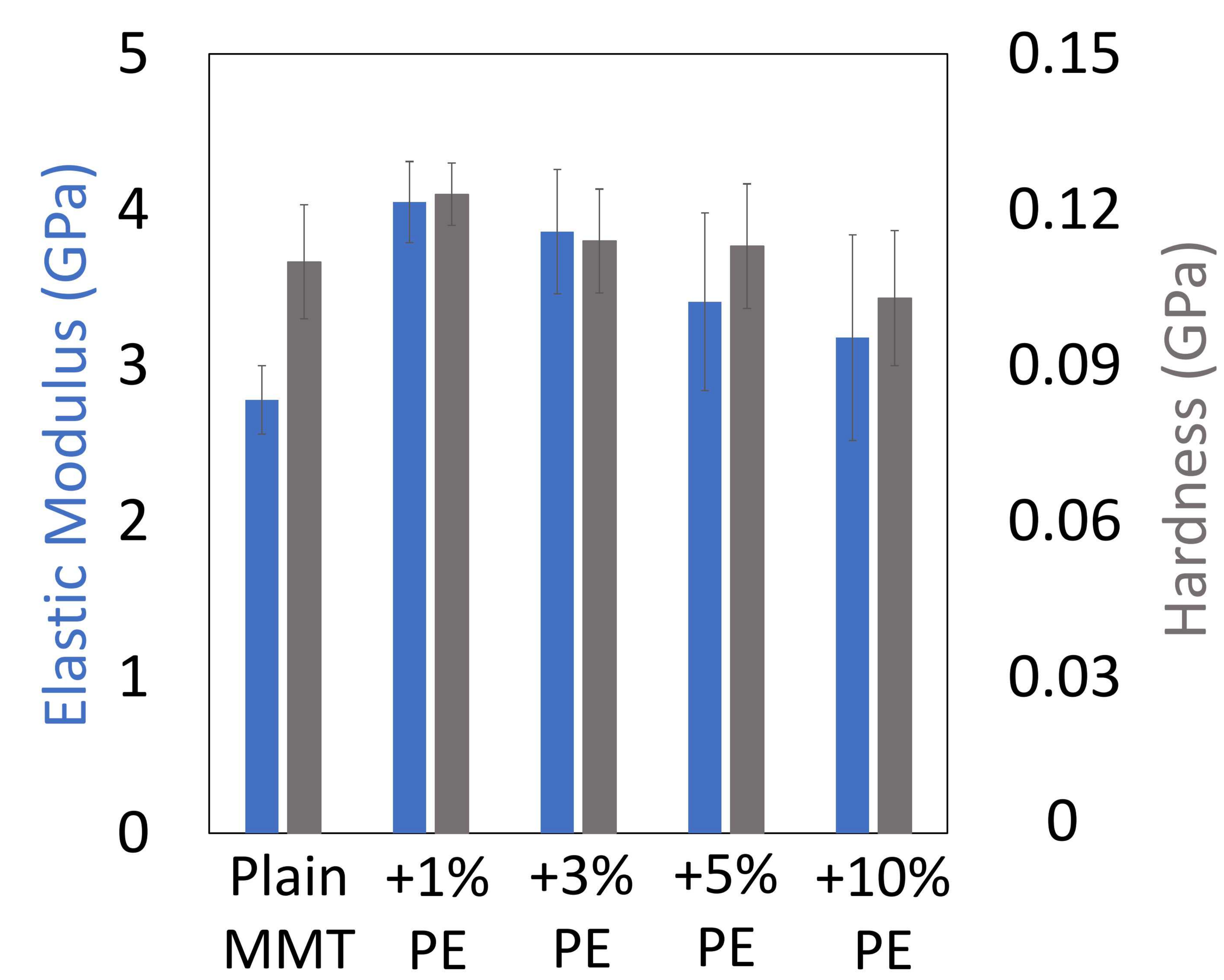
Destruction of layered structure (exfoliation) degrades mechanical properties.

- Pellet preparation – Pressure, pellet thickness



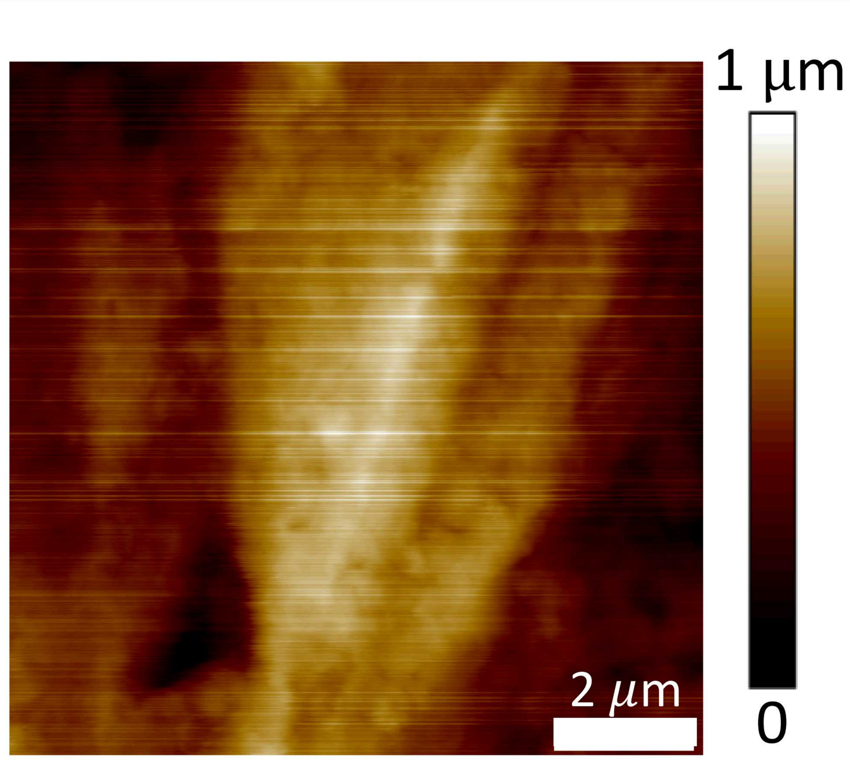
Pellets can be made stronger with more pressure and can be made thin without losing integrity.

- Composition – Polyethylene can be added to increase modulus/hardness

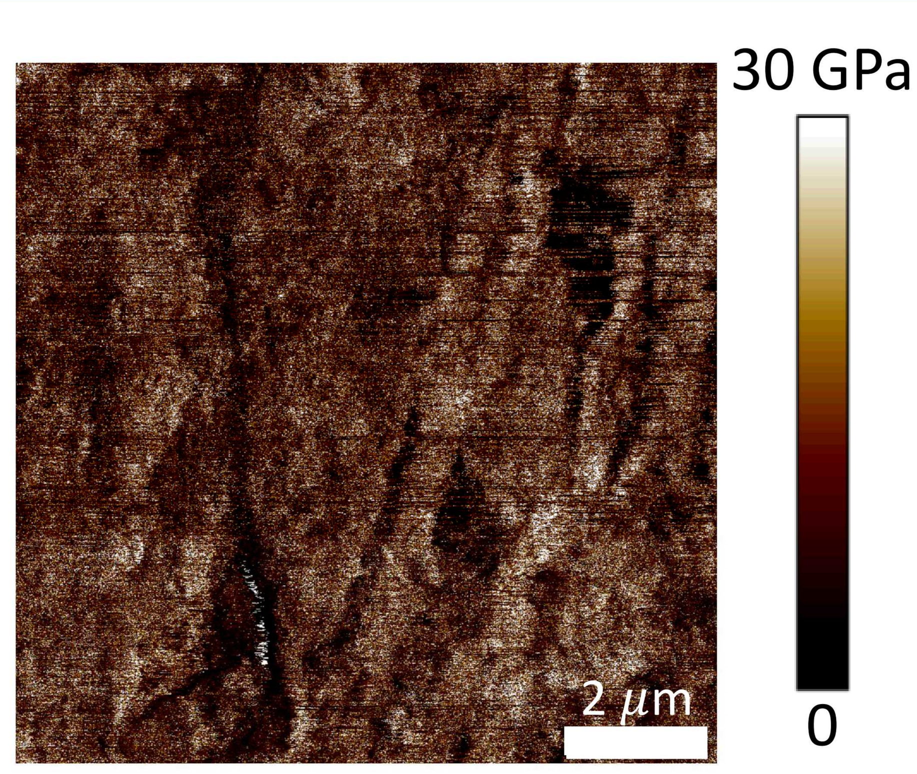


Incorporation of small amount of chemically inert polymer improves mechanical integrity.

❑Nanomechanical mapping



Topography



Elastic Modulus

Small deformations made with an AFM cantilever can extract elastic modulus with sub-micron spatial resolution

Local mechanical properties can be correlated with surface features (pores, impurities, roughness)!

❑ Conclusions and Future Work

Conclusions:

- The mechanical properties of sodium ion conductors can be tuned by controlling:
  - Extent of clay exfoliation
  - Pressure during pellet formation
  - Polymer content in clay composites
- Mechanical properties can be correlated with topographical features to further inform design decisions

Future Considerations:

- Can MMT be used as an ion conductor in other battery chemistries?
- Can other polymers further improve mechanical properties in composites?
- Can MMT platelets be oriented preferentially in thru-plane direction?

❑ Acknowledgements

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