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Sandia National Laboratories

Thermomechanical Properties of Polyurea Nanocomposites Over Extreme Strain Rates

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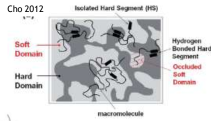
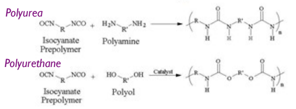
Introduction

Polyurea is an extremely tough polymer used commercially to increase durability, corrosion, or impact resistance of surfaces.

Hydrogen bonding and a phase-segregated network nanostructure in polyureas resist deformation and damage, especially at high strain rates and high strain levels.



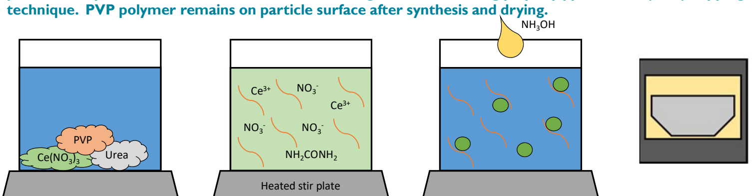
Research Goal: Engineer a particle-filled polyurea nanocomposite and assess its mechanical energy absorption over a wide range of strain rates (0.1 – 10,000 Hz).



Hydrogen bonding is absent from polyurethanes, another encapsulant commonly used for energy absorption.

Nanoparticle Synthesis

Explore nanoparticle synthesis to obtain control of nanoparticle size and facilitate dispersion into polymer phase. Nanoparticle-sized ceria can be created in large batch sizes using polyvinylpyrrolidone (PVP)-capping technique. PVP polymer remains on particle surface after synthesis and drying.

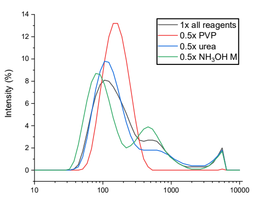


1) Dissolve polyvinylpyrrolidone, cerium nitrate, and urea into water

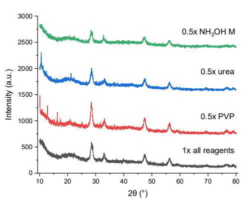
2) Heat solution to 65 °C

3) Precipitate colloidal cerium-based particles using ammonium hydroxide

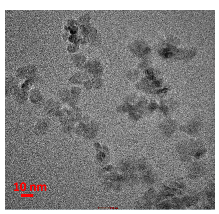
4) Dry ceria at 110 °C after centrifugation



Particle size can be controlled by changing reagent concentration



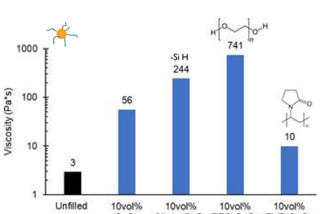
X-ray diffraction verifies CeO_2 synthesis



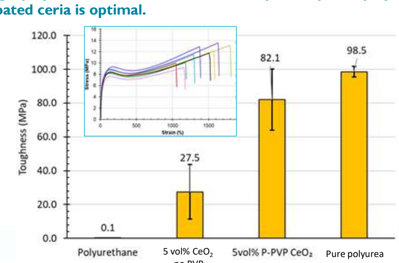
Primary particle size of large batch material is near 10 nm

Particle Incorporation

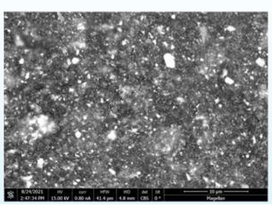
Explore nanoparticle surface modification using a polymer surfactant to increase compatibility with polymer phase and facilitate particle dispersion. PVP-coated ceria is optimal.



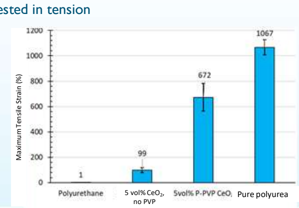
Of all polymers, surface modification with PVP creates best compatibility with polyurea precursors, as measured through viscosity of the particle-filled suspension



Poor particle-polymer compatibility results in degraded composite toughness and maximum tensile strain when tested in tension

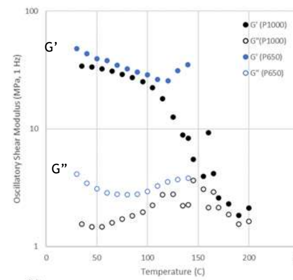


Up to 35 vol% PVP-ceria particles possible in polyurea nanocomposites.

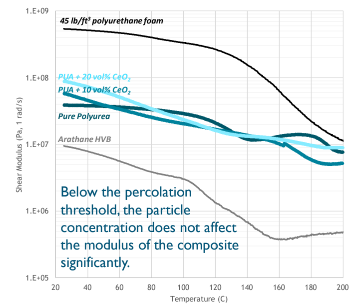


Polyurea Dynamics

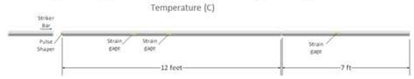
The strain and strain-rate dependence of the modulus of polyurea is important to characterize for design of energy damping encapsulants and barriers.

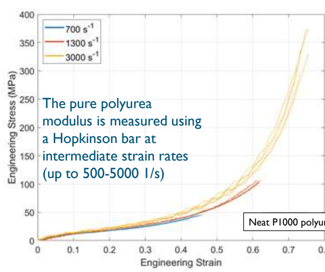


As the soft domain molecular weight is decreased from P1000 to P650 to P250, the modulus and glass transition temperature (Tg) increase. Viscoelasticity and energy damping are maximized near Tg where the storage and loss shear moduli are both significant.

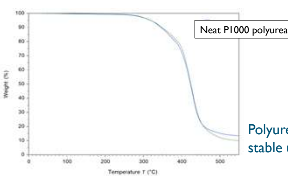


Below the percolation threshold, the particle concentration does not affect the modulus of the composite significantly.

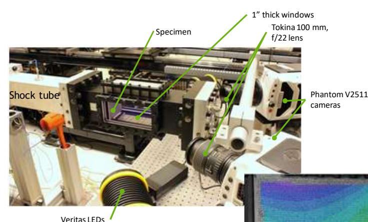


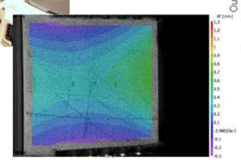


The pure polyurea modulus is measured using a Hopkinson bar at intermediate strain rates (up to 500-5000 1/s)

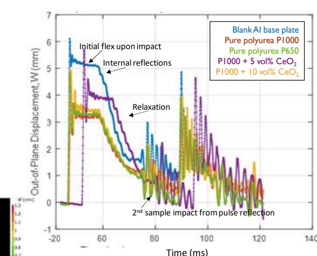


Polyureas are thermally stable up to ~350 C





Shock tube imposes a mach 2.5 blast of air on a 4x4 inch, 1 mm thick plate of aluminum, covered with a 1.5 mm thick polyurea sample and deflection is measured using DIC.

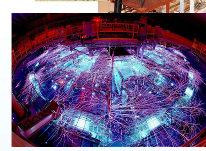


The bare aluminum plate deflects the most, whereas polyurea composites damp the impact.

Conclusions and Future Work

The ability for polyureas to damp mechanical energy are promising. By surface modifying particles with PVP, polyurea nanocomposites can be made. Nanocomposites can be molded or cured into any shape and perform well in damping mechanical energies.

Unknown are mechanical properties under extremely high strain rates (> 10^7 1/s) and nanostructural behavior with different nanoparticle loadings. To answer these questions, polyurea samples will be tested in the Sandia National Laboratory SPHINX and Z-machine under electron beam and X-ray radiation pulses, respectively.



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