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Residual Internal Stress Optimization for Thermoset Resin using Fiber Bragg Grating Sensors

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U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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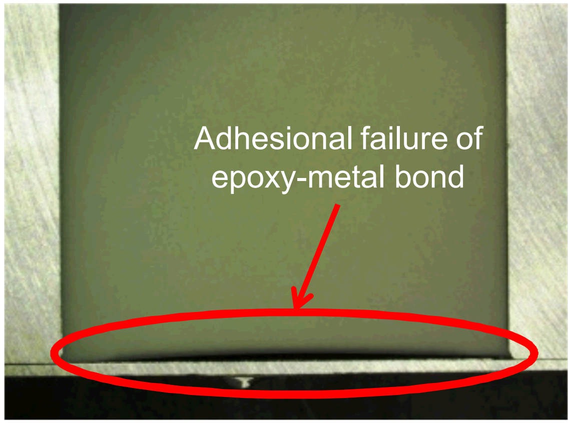
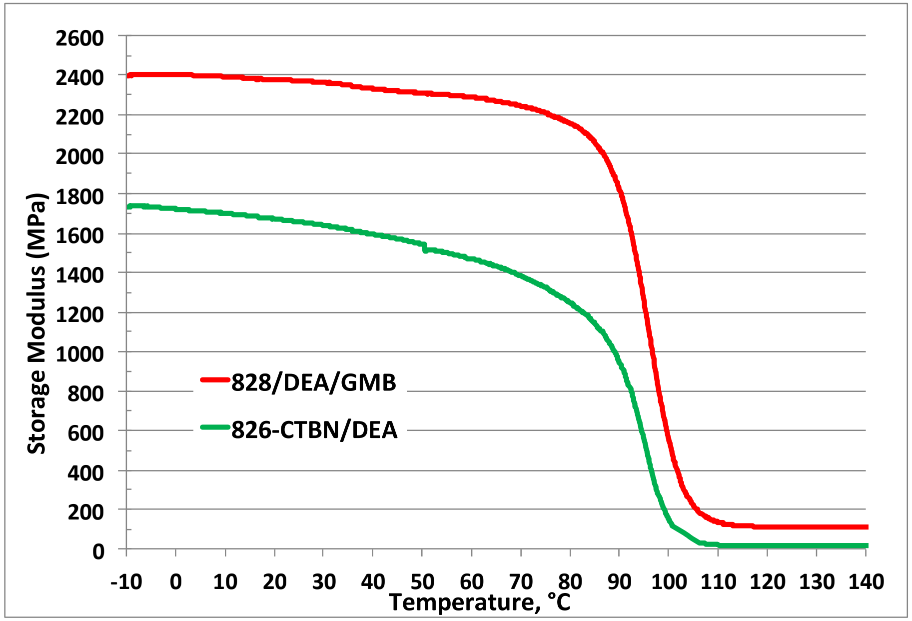
Epoxy Resins and their Stresses

- Epoxies provide protection for sensitive electronics
  - High voltage, shock, humidity, thermal environments
  - Mechanical and electrical properties of an epoxy system are key to success of component
    - These properties depend on the extent of cure of the epoxy
- Epoxies are often cured at elevated temperatures in order to speed reaction mechanisms that allow network formation
  - Stresses can develop as a result of cure that can result in adhesional or cohesive failures of the epoxy and ultimately the electronic components
- **Goal is to understand the development of these stresses in our system and minimize their impact**



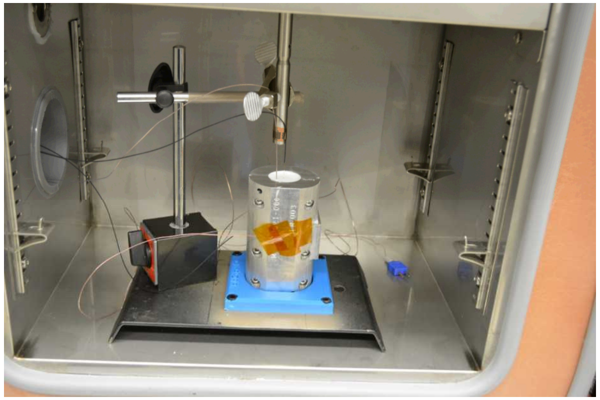
Epoxy Resins and their Stresses

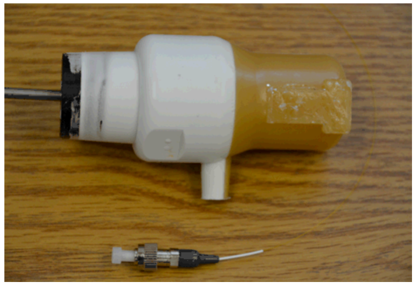
- Two systems of epoxies
  - Epon 828 (diglycidyl ether of bisphenol A) cured with diethylamine (DEA) and filled with glass microballoons
  - Epon 826 cured with DEA and filled with carboxy-terminated butadiene nitrile (CTBN)
- Strain sources:
  - Post-gelation cure shrinkage
  - Thermal expansion mismatch
  - Shear stress at embedded geometry
- As epoxy cures its modulus evolves and viscoelastic response to strains changes
  - Modulus evolution will be tied to time and temperature of cure profile
- **By controlling the cure profile, we can reduce the stresses in the encapsulation system**

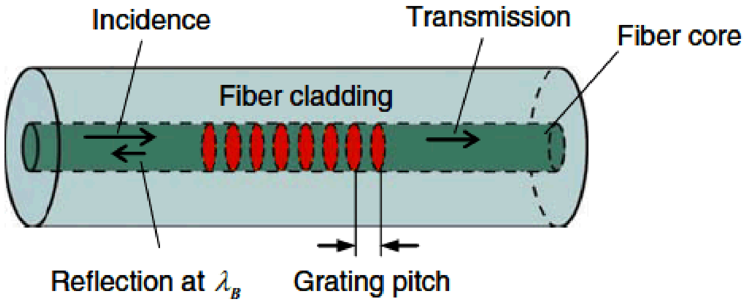


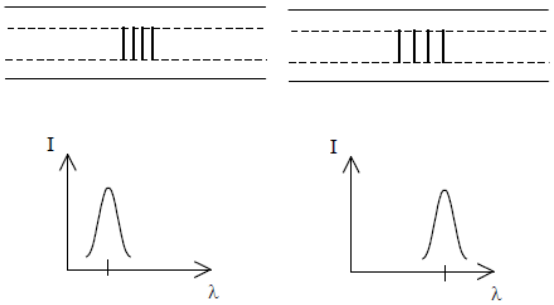
Fiber Bragg Grating Sensors

- Fiber Optic Bragg Grating Sensor (FBG)
  - Allows for embedded measurements of strain in epoxy as it cures
  - Can be removed from the mold
  - Can be tested with real geometry



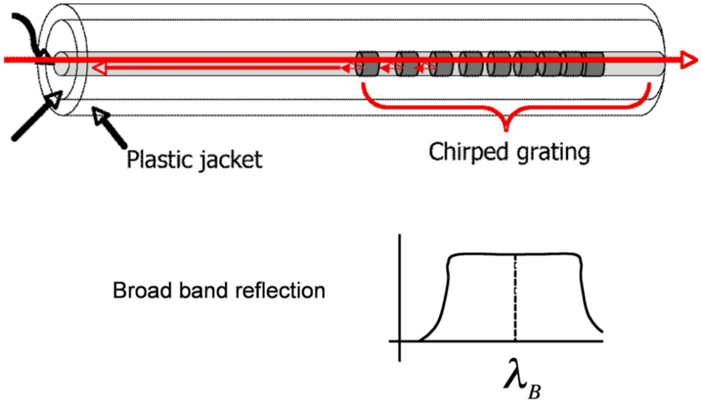






Reflected peak at lower center wavelength

Reflected peak at higher center wavelength



Simplified and Constrained Geometry Tests

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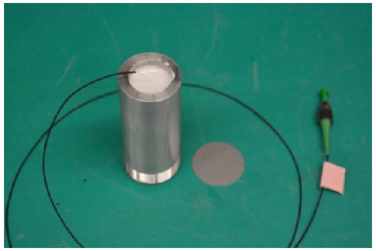
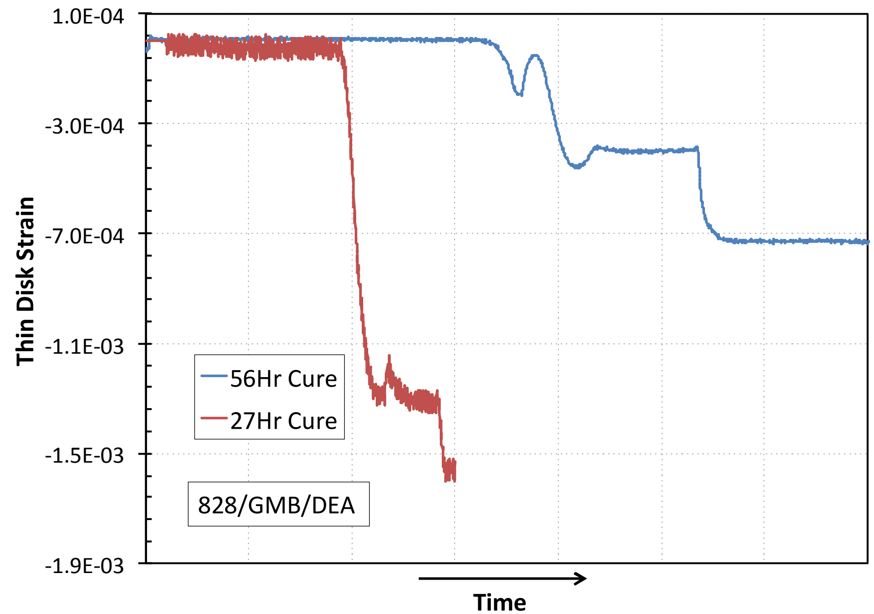
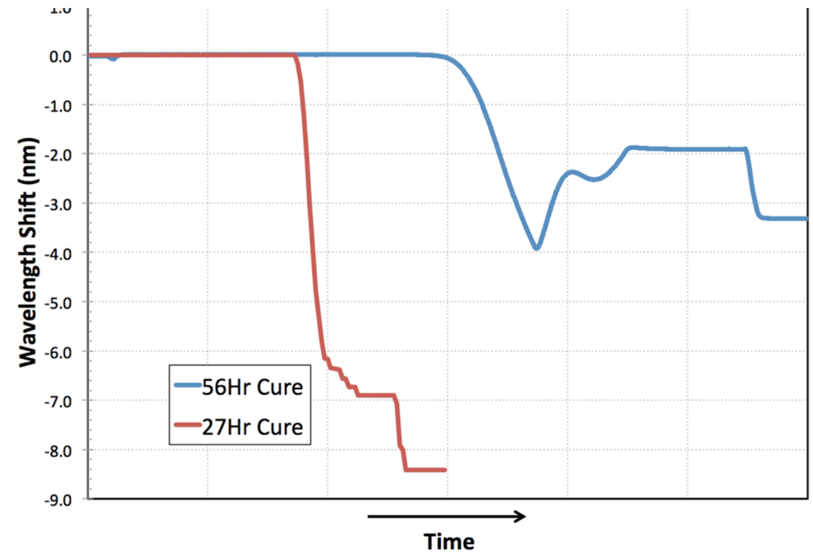
- Pop-off tube geometry consists of Aluminum cylinder with thin disk at bottom
  - Allows for strains in epoxy to be measured with strain gauge as well as fiber optic sensor
    - Strain gauge mounted to thin disk that will flex as the epoxy shrinks during cure
    - Fiber optic sensor mounted vertically through center of cylinder
  - Sides of cylinder are sand-blasted to promote adhesion and constrain epoxy
- Analyzed two different non-isothermal cure profiles (27hr and 56hr)
  - 27hr cure had higher initial hold temperature than the 56hr allowing for faster reaction
  - Both cures had similar post-gelation ramp rate, max temperature, hold time, and cool-rate

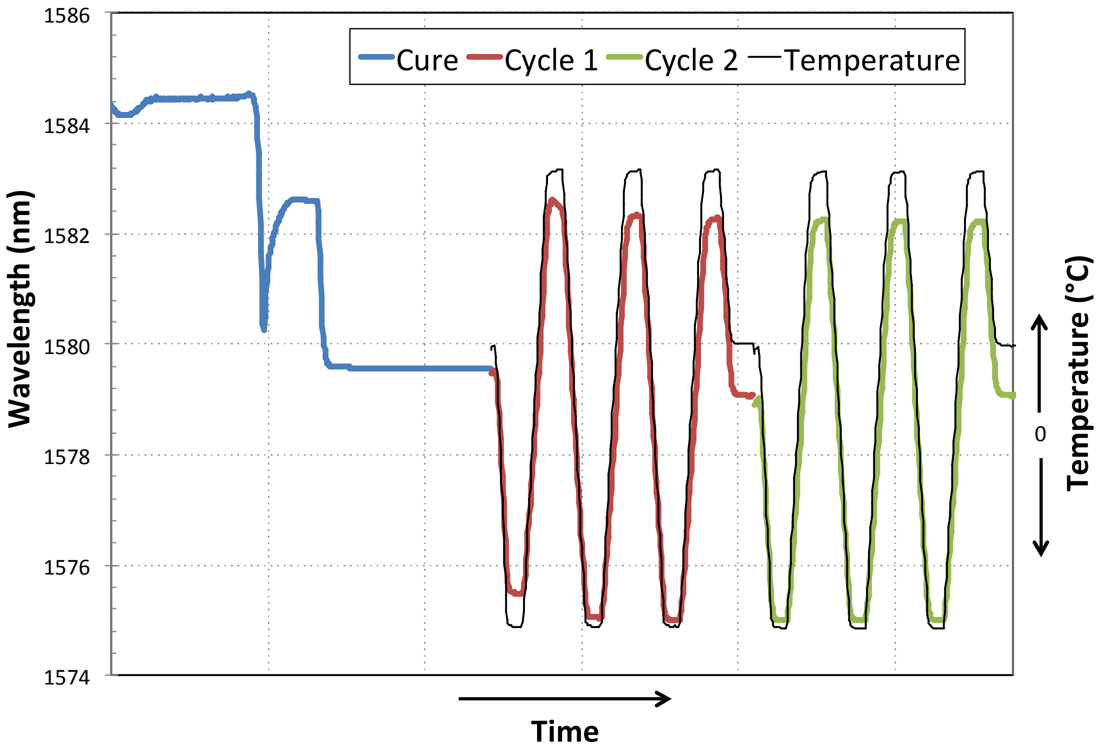


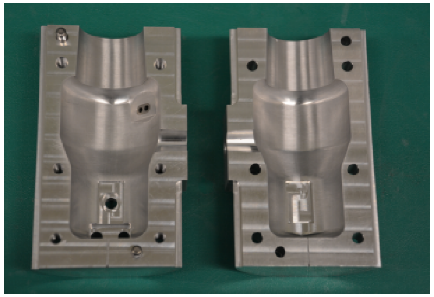




Production Mold

- Analyzed stresses in production mold through both cure and thermal cycling
- Stresses develop during cure from interaction between component and mold
  - Epoxy not able to fully relax
  - Increased stress at colder temperatures
- After first heating near Tg epoxy undergoes volume relaxation
  - Translates to fiber as compression
  - Continued cycling does not show added compression





Interacting with Internal Components and different Epoxy Systems

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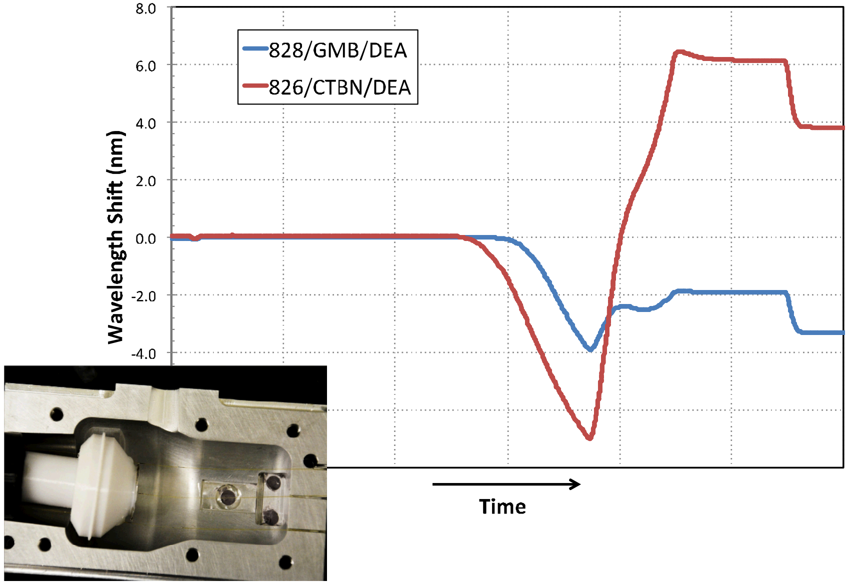
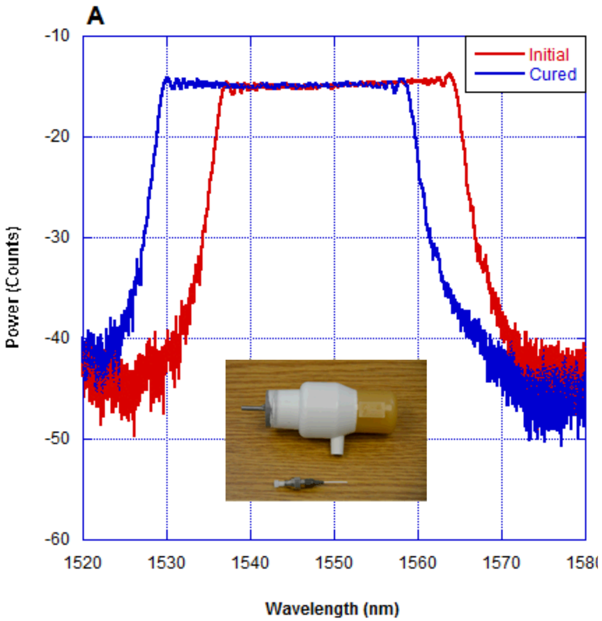
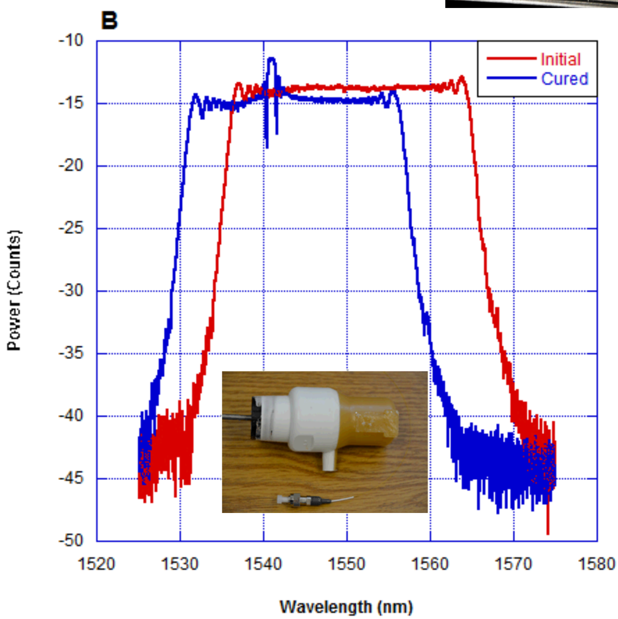
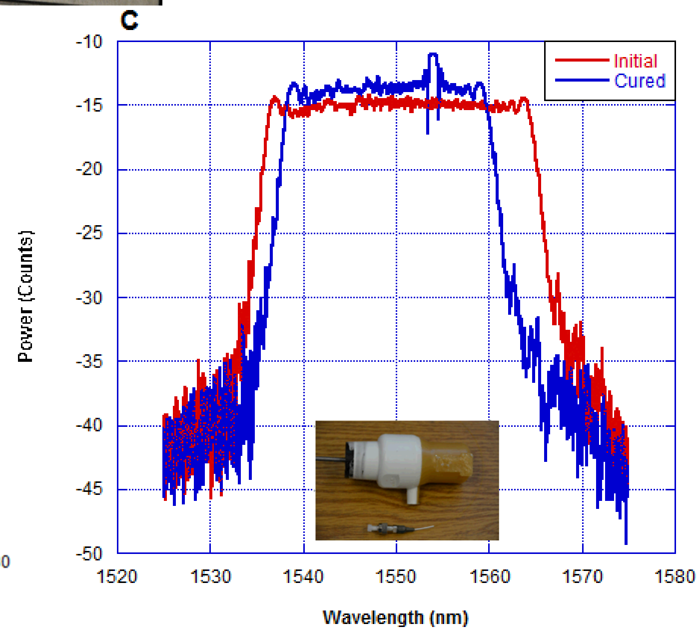
- Added an internal component as well as multiple epoxy systems as seen in real component
- Chirped fiber enables identification of interface layer
- Identified that decreasing strain in one epoxy system may lead to adverse impact from other epoxy system









Discussion

- Fiber optic Bragg Grating sensors offer unique method to understanding stress development in epoxy systems
- Powerful tool enabling variety of new experiments
  - In situ information on stress in real geometries at various locations
  - Understanding of stresses near epoxy interfaces in binary systems
- Continuing to develop modeling tools to help with data interpretation
  - Working to better understand epoxy reaction kinetics and how it relates to the production of stresses

Acknowledgements

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- Shawn Dirk

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Thank you for attending!

System Details

- Fiber optic system:
  - Micron Optics sm125-500 (4-Ch, 80nm wavelength range, 2Hz scan rate)
  - Micron Optics si225-500 (8-Ch, 160nm wavelength range, 1kHz scan rate)
- Sensors:
  - Micron Optics os1100 FBG
  - Timbercon Inc and O/E Land Inc. custom-made 10mm chirped fibers