Simultaneous Measurements of Evolution of Effective Chemical Shrinkage and Modulus during Polymerization

Goal and Approach

- To develop and implement an integrated method using fiber Bragg gratings embedded in a polymer substrate
  - To simultaneously measure the evolution of the effective chemical shrinkage and Young’s Modulus of polymers during the polymerization process

Goal and Approach

- No practical techniques can measure...
  - Both properties simultaneously (correlation of results between different experiments can be difficult)
  - Young’s Modulus during curing (only the shear modulus can be found)
  - Effective chemical shrinkage (only the total chemical shrinkage can be found)

- Implementation of this novel technique would allow for the rapid characterization of new polymeric materials to help in predictive modeling and design optimization
Proposed Method & Implementation

• Specimen sizes chosen to maximize measurement sensitivity and to minimize heat generation effects during curing

• Mold of silicon rubber tubing and Teflon used to negate any constraints to polymer while curing, align FBG and thermocouple

Environmental Chamber

FBG-IS

Optical fiber

illuminates the fiber and receives the reflected spectrum

Ethernet cable

TC Specimen

Experiment Results

• BW shifts of C-1 and C-2 after the gelation point used to calculate the evolution of the modulus and effective chemical shrinkage throughout the curing process

• Throughout curing, at the gelation point the BW begins to decrease from deformation induced stresses

FBG cured around an underfill material in two different configurations

C-1: \( r_p = 38 \) \( r_f \)

C-2: \( r_p = 19 \) \( r_f \)
Validity of Method

• The evolutions of the effective chemical shrinkage and Young’s Modulus were used to predict the time dependent warpage of a bi-material strip during the curing process.

\[ w(t) = \int f(t,x,z) \left( E_p(t) \Delta \epsilon(t) \right) dt \]

Validity of Method

• The prediction was verified using Twyman-Green Interferometry.

Twyman-Green warpage data agrees well with prediction calculated from evolutions.

\[ w = \frac{N}{2n} \lambda \]

Conclusion

• A FBG-based technique was proposed and successfully implemented to simultaneously measure the evolution of the effective chemical shrinkage and modulus of an underfill material during the curing process.

• The proposed technique was validated via an independent experiment using a bi-material strip.

• The chemical shrinkage and modulus evolutions can be used to predict the behavior of package assemblies to further optimize the manufacturing process.