IOWA STATE UNIVERSITY

Materials Science & Engineering Department

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Preliminary Oral Examination
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"Dielectric Properties and Degradation Monitoring in Polymer-Matrix Structural Composites"

New aircraft and terrestrial vehicles increasingly contain more components made from polymer matrix composites (PMCs), in both primary and secondary roles. Beyond the weight savings that PMCs provide over metals, they are being developed for energy storage in addition to their structural role. Meeting these demands requires not only new processing and synthesis techniques, but new models to describe and predict material properties, as well. As these new components are exposed to a variety of environments while in use, alternative monitoring techniques that emphasize the role played by polymer matrix degradation in the failure of these parts are also needed.

The present work investigates changes in surface chemistry of a bismaleimide (BMI)/glass-fiber laminate, one candidate for structural energy storage, due to accelerated thermo-oxidative aging. Composite samples were isothermally aged at various temperatures whose selection was guided by degradation steps revealed through thermo-gravimetric analysis. Compression tests and permittivity measurements were performed on aged samples to assess the extent of property degradation, and shared trends between the two were identified. Capacitive sensing is suggested as a method for nondestructive monitoring of thermo-oxidative aging in this system.

In addition, to adequately describe some surprising properties that are observed in PMCs reinforced with nanoscale filler particles, a three-phase theoretical model is proposed that is suitable for describing the effective permittivity of polymer-matrix composites containing spherical nanoparticles. The model accounts for the presence of an interphase region, which takes on a dominant role in influencing properties of nano-filled composites due to the large surface-area-to-volume ratio of nanoscale fillers. The model is applied to permittivity data measured on a silicon/bisphenol E cyanate ester nanodielectric and a low-density polyethylene/alumina nanodielectric. While the data sets are shown to lie outside the range of the two-phase models that do not account for the interphase, the proposed three-phase model successfully bounds both data sets.

In future work, kinetic modeling of thermogravimetric data will be conducted on the BMI/glass-fiber system to obtain the activation energies of its thermal degradation mechanisms. In addition, photoacoustic Fourier transform infrared spectroscopy will be used to detect surface chemistry changes due to degradation and correlations with observed changes in mechanical properties will be sought. Finally, similar thermal aging followed by mechanical and infrared spectral characterization will be performed on a toughened epoxy/carbon-fiber composite system.