5. Conclusions

In the research described here, a new design was investigated for an optical fiber-based sensor for the in-situ measurement of the viscoelastic properties of thermosetting polymer resins during cure. Preliminary experiments presented here indicate that the sensor will have application in detecting viscoelastic transitions during the cure of thermoset-matrix composite materials. By coupling a fiber optic strain gage to a piezoelectric actuator, the resulting assembly is capable of detecting the change in loss tangent and absolute shear modulus which accompany the gelation and vitrification of the resin. An analytical model of the mechanics of the sensor was derived, which predicts that measurements of shear storage modulus (G’) and loss modulus (G’’), or equivalently, the loss tangent (tan delta) and the absolute shear modulus (|G*|), can be obtained if the sensor is packaged in a housing that establishes fixed boundaries at a known distance from the sensor. In addition, the model suggests that a sensor without a housing will yield estimates of the loss tangent (tan δ) as well as relative changes in absolute shear modulus.

Several prototype sensors without boundaries were fabricated and tested in a room temperature curing epoxy and in a high-performance epoxy designed for resin transfer molding applications. The change in loss tangent and absolute shear modulus correlated well with thermodynamic and rheological changes that had been previously measured in a representative sample of the same epoxy, using dynamic mechanical analysis and differential scanning calorimetry. Sensor outputs appeared to be repeatable, within the variation in properties between the different epoxy batches used. These results show that the sensor may be used to detect the occurrence of viscoelastic transitions during processing of a neat resin.

Prototype sensors employing a piezoelectric actuator laminate known as THUNDER® were demonstrated in tests during the cure of epoxy-impregnated prepreg laminates. Despite the presence of noise that may result from slip-stick motion of the actuator, the sensor captured changes in the loss tangent and absolute shear modulus consistent with gelation.

Miniature ceramic lead-zirconate-titaneate (PZT) tubes were developed in order to miniaturize the fiber optic sensor. The tubes were fabricated by extruding a suspension of PZT in propanol onto a polyester fiber, evaporating the propanol, and burning out the polyester fiber while sintering the ceramic. The resulting tubes were sufficiently small to be used to be integrated into the assembly of fiber optic strain gages. Electroding and poling of the tubes have yet to be demonstrated.