ABSTRACT

Composite manufacturing is influenced by several processing parameters including temperature, mold pressure, processing time, and complex curing kinetics. Regarding quality control, the autoclave provides a standard for producing aerospace-grade composite parts. A key feature of an autoclave is the real-time feedback system of temperature and pressure sensors. Though the autoclave has been effective, it is also expensive to purchase, operate, and maintain. In addition, the manufactured part would need to fit the autoclave's dimensions. To accelerate the use of composites, new technologies need to emerge to ensure quality control without the need for expensive and restrictive equipment and tooling.

This research will introduce a monitoring system that uses carbon nanotube yarns (CNTys) as noninvasive curing sensors for out-of-autoclave (OOA) composite manufacturing. CNTys have already proven to map temperature and pressure changes in a vacuum bag molding. The yarns have also detected resin flow and thermal shrinkage that occurs during curing. The quality of a composite relies on the curing process, and the goal of this study is to correlate theoretical curing data with empirical sensing data from the yarns. An unsaturated polyester resin (UPR) was chosen to train a potential model, as UPR does not require elevated temperatures. Baseline correlations between curing and the electrical resistance of the yarns were made in this research without the external influence of temperature, which the yarns can also detect. To vary curing quality, three catalyst concentrations of methyl ethyl ketone (0.75 wt. %, 1.25 wt. %, and 2 wt.%) were used to cure UPR. Differential Scanning Calorimetry (DSC) was used to measure and calculate the average degree of curing at each catalyst concentration. Sensing experiments were also performed using the same concentrations to uncover the yarn's resistance responses. with the corresponding sensing responses from yarns embedded in UPR. As UPR solidifies, the yarns experience stress from thermal shrinkage and respond electrically. With both DSC and sensing data, the aim is to establish data correlations that can be used to predict the quality of a composite part.

There were clear differences in the DSC data, which present heat flow during curing as an exothermal peak due to different setups. If DSC experiments are conducted on a fully cured resin, no exothermal peak will occur. For the 0.75wt. %, 1.25 wt. %, and 2 wt. % catalyst concentrations, the average for the estimated degree of cure was measured as 81.29%, 91.6%, and 97.84% via DSC, respectively. The corresponding sensing responses, which are expressed as an average residual resistance change, were measured as 4.5%, 6.43%, and 7.71%. There are preliminary correlations between the DSC data and sensing response; moreover, the sensors can detect when a

resin is uncured. Another approach to understand their correlation was made by incorporating a distinct factor, that is temperature. Explored manipulating a glass fiber prepreg curing process by altering the curing temperature, 154°C, 134°C, and 114°C sets using vacuum bagging on temperature chamber. The goal of this research is to establish a framework to use CNT yarns for composite manufacturing quality control.