CARBON FIBER POLYMER-MATRIX COMPOSITES AS STRAIN AND DAMAGE SENSORS

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INTRODUCTION

Real-time damage assessment for the purpose of real-time failure prediction and timely maintenance of critical structures and machinery is in increasing demand, as it provides cost savings and enhances safety. Damage assessment has been most commonly achieved in real time by the use of remote vibration sensors, embedded/attached strain gages, or eddy current testing. In this paper, real-time damage assessment is provided by measurement of the electrical resistance. There are no sensors, as the part is its own sensor. The electrical contacts need only be at the edges of the part in order for the whole part to be assessed; they may be permanent or temporary. Damage is associated with an irreversible increase of the electrical resistance. The degree of damage is described by the fractional irreversible increase in the electrical resistance. The technique is demonstrated in this paper by damage assessment of carbon fiber reinforced epoxy.

Electrical resistance measurement had been previously used for damage assessment in a ceramic-matrix silicon carbide whisker composite [1] and in polymer-matrix carbon black composites [2].

EXPERIMENTAL

The electrical resistance R was measured using the four-probe method and a Keithley 2001 multimeter while cyclic tension or cyclic compression was applied. Silver paint was used for electrical contacts. The four probes consist of two outer current probes and two inner voltage probes. The resistance R refers to the sample resistance between the inner probes. The resistance was measured along the stress axis. The current (DC) used was 0.5-1.0 mA; the voltage used was 2.0-2.4 V. The displacement rate was 1.0 mm/min under tension and 0.5 mm/min under compression. The strain under tension was measured by a strain gage; the strain under compression was measured using the displacement.

The composite samples had epoxy (Epon 9405 bisphenol A epoxy resin and 9470 non-MDA aromatic amine curing agent, from Shell Chemical Co.) as the matrix and short carbon fibers (5 mm long, resistivity 3 x 10^{-3} Ω.cm, pitch-based, unsized, from Ashland Petroleum Co., Ashland, Kentucky) as the filler. The composites were fabricated by mixing the fibers with the epoxy resin, heating the mixture in a vacuum furnace at 100°C for 3 h to remove bubbles, and then hot pressing at 150°C and 1.6 MPa for 30 min.

CONCLUSION

Real-time damage assessment by electrical resistance measurement was demonstrated for polymer-matrix short carbon fiber composites. Even when the strain was reversible, damage occurred, as shown by irreversible increase in the electrical resistance. Near or above the elastic limit, fiber breakage occurred and caused additional irreversible resistance increase. The fractional irreversible resistance increase was much higher under compression than tension at the same stress amplitude (ratio of the maximum stress to the fracture stress) due to the greater strain under compression than tension. The fractional irreversible resistance increase increased with increasing stress amplitude, whether below or above the elastic limit.

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