Experimental Design To Probe
Autonomic Restoration Of Electrical Conductivity

S.L.B. Kramer1,5, B.J. Blaiszik1,5, S.A. Odom2,5, M.E. Grady1,5, D.A. McIlroy1,5,
J.S. Moore2,5, S.R. White1,5, and N.R. Sottos1,5

1Department of Materials Science and Engineering, 2Department of Mechanical Science and Engineering, 3Department of Aerospace Engineering, 4Beckman Institute, University of Illinois at Urbana-Champaign

Overview

Objective:
Characterize microcapsule-based approaches to autonomic restoration of electrical conductivity in mechanically damaged circuits

Attributes of the Experimental Method:
• Quantification of the loss and restoration of electrical conductance in the circuit
• Reliable mode of mechanical damage to conductive pathways in a model circuit
• Model circuit that enables trigger of the microcapsules during damage event

Wheatstone Bridge for Measuring Variable Resistance:
Specimen circuit acting as one arm (R1) of the bridge

Vc: Held constant @ 5.00 V
V1: Vc for fully broken R1
V2: Vc for undamaged circuit

Vnorm(t, V1) = V1(t) - V2

Healing efficiency is Vnorm after fracture.

Conductive Healing Systems

Examples
• TTF-TCNQ
• Ga
• Ga-In
• Ga-In-Sn
• Field's metal

Examples
• Carbon particles
• Silicon particles
• Ag particles

Healing Efficiency

Four-Point Bend Protocol of Multilayered Specimen

Loading Apparatus
• Notched Glass, 1-mm thick
• Epoxy with microcapsules, 250-µm thick
• Au / Cr patterned lines, 110-nm thick, connected to Wheatstone Bridge
• Glass, 1-mm thick
• Epoxy 250-µm thick
• Acrylic preventing complete specimen fracture, 1.5-mm thick
• Crack: propagates from notch to acrylic layer and delaminates along the epoxy/ acrylic interface; 5-10 µm crack opening at the Au/Cr layer after unloading

Complete conductance loss due to mechanical damage with fast, highly efficient healing for the conductive liquid metal system

Representative Data

Assessment of Autonomic Restoration of Electrical Conductivity

Control specimen without microcapsules

Specimen with Ga-In liquid metal-filled microcapsules

Short timescale voltage data collected by a high-speed oscilloscope at 2.5 MHz

99% healing efficiency in 20 µs for Ga-In healing specimens vs. 0% healing for control specimen

Conclusions

Successful development of reliable mechanical testing protocol for characterizing the autonomic restoration of electrical conductivity using microcapsule-based healing approaches

• Wheatstone Bridge voltage data for quantifying healing efficiency
• Four-point bend testing of a model circuit multilayer specimen
• Demonstration of healing by the Ga-In system using the experimental protocol, with 99% healing efficiency in 20 µs

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