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Mechanical Properties of Microcapsules Used in a Self-Healing Polymer

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Abstract The elastic modulus and failure behavior of poly(urea-formaldehyde) shelled microcapsules were determined through single-capsule compression tests. Capsules were tested both dry and immersed in a fluid isotonic with the encapsulent. The testing of capsules immersed in a fluid had little influence on mechanical behavior in the elastic regime. Elastic modulus of the capsule shell wall was extracted by comparison with a shell theory model for the compression of a fluid filled microcapsule. Average capsule shell wall modulus was 3.7 GPa, regardless of whether the capsule was tested immersed or dry. Microcapsule diameter was found to have a significant effect on failure strength, with smaller capsules sustaining higher loads before failure. Capsule size had no effect on the modulus value determined from comparison with theory.

Keywords Self-healing composite · Microcapsule · Compression · Urea-formaldehyde · Modulus · Strength

Introduction

Microcapsules containing liquid healing agent are a critical component of self-healing polymers [1, 2]. Healing is accomplished by incorporating the microencapsulated healing agent and a catalyst within an epoxy matrix. An approaching crack ruptures embedded microcapsules, releasing healing agent into the crack plane through capillary action. Polymerization of the healing agent is initiated by contact with the embedded chemical catalyst, bonding the crack faces. The rupture of microcapsules is the mechanical trigger to the healing process and without it, no healing occurs. This system has proven to be highly effective at healing cracks in both quasi-static [1] and fatigue [3–6] loading.

An optimal combination of microcapsule and matrix properties is necessary to ensure mechanical triggering when the material is damaged; if the shell wall is too thick the microcapsule will not rupture readily, preventing the release of healing agent. On the other hand, if the shell wall is too thin, the capsules not only are fragile, but also allow diffusion of the healing agent into the matrix. Other key parameters for efficient healing agent delivery are the elastic stiffness, the failure strength of the capsules, and the fill content, which is the percentage of the capsule core volume occupied by the encapsulated fluid.

Because the variable set describing the behavior of microcapsules in a matrix is large, micromechanical modeling can be used to investigate the interaction of a crack with a microcapsule. In previous work, Eshelby–Mura equivalent inclusion method was chosen to perform the modeling of the crack-capsule interaction [1]. Model predictions reveal that that the capsule-to-matrix stiffness ratio influences the crack propagation path in close proximity to the capsule. A capsule with a higher elastic modulus than the surrounding matrix creates a stress field that tends to deflect the crack away from the microcapsule. Conversely, a more compliant

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