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# Elastic interaction of interfacial spherical-cap cracks in hollow particle filled composites

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ABSTRACT

This work analyzes the elastic interaction between two spherical-cap cracks present along the outer surface of a hollow particle embedded in a dissimilar medium under remote uniaxial tensile loading. A semi-analytical approach based on an enriched Galerkin method is adopted to determine stress and deformation fields as functions of particle wall thickness and cracks' configuration. The present analysis is limited to multiple interfacial spherical-cap cracks; that is, crack propagation is restrained to the particle-matrix interface and possibility of crack kinking in the matrix is not considered. Interfacial crack growth characteristics, conditions for stable crack propagation, equal crack growth, and shielding are established through energy release rate analysis. The study is relevant to the analysis of tensile and flexural failure of syntactic foams used in marine and aerospace applications. Results specialized to glass-vinyl ester syntactic foams demonstrate that particle wall thickness can be used to control crack stability and growth characteristics as well as tailoring the magnitude of the shielding phenomenon. Predictions are compared to finite element findings for validation and to results for penny-shaped cracks to elucidate the role of crack curvature.



## 1. Introduction

Syntactic foams are composite materials obtained by dispersing hollow particles in a matrix (Narkis et al., 1984) with the twofold intent of improving properties and reducing density of the matrix. Selection of constituent materials, particle volume fraction, and particle wall thickness allows for tailoring the composite properties (see for example Gupta et al., 2010; Islam and Kim, 2007; John et al., 2007). The presence of porosity enclosed inside thin inclusions improves dimensional stability by providing low moisture absorption and thermal expansion (see for example Rohatgi et al., 2006; Sauvant-Moynot et al., 2006).

Designing marine and aerospace load bearing structures requires a thorough understanding of structure-property correlations and failure mechanisms in syntactic foams. Polymer matrix syntactic foams have received great attention for their wide application spectrum (see for example Bardella and Genna, 2001a; Gladysz et al., 2006; Gupta et al., 2010). Experimental studies on compressive response of glass-vinyl ester and epoxy syntactic foams show that failure is largely due to particle crushing (Gupta et al., 2010; Kim and Plubrai, 2004) whereas the particle-matrix interface plays an important role in determining the failure mechanisms under tensile and flexural conditions (Gupta et al., 2010; Tagliavia et al., 2010a; Wouterson et al., 2005). Scanning electron micrographs of tensile fracture surfaces show interfacial failure and curvilinear deformation marks in the matrix (see for example Kishore et al., 2005; Koopman et al., 2006). Similar features are also found in solid particle filled composites (see for example Lee and Yee, 2001; Pawlak and Galeski, 2002).

Theoretical studies have elucidated the role of particle wall thickness and volume fraction on the elastic properties of syntactic foams by considering perfect bonding at the particle-matrix interface (see for example Bardella and Genna, 2001b; Huang and Gibson, 1993; Marur, 2005; Porfiri and Gupta, 2009). These studies are further extended to include compliant interfacial layers in Marur (2009); within this model, full contact is assumed to be present at the particle-matrix interface. This approach is not applicable to the analysis of interfacial cracks formed during debonding, which is the failure mechanism in syntactic foams under tensile and flexural loading. Such failures are analyzed in a recent work where the problem of a single partially debonded inclusion embedded in an infinite matrix and subjected to uniaxial tensile loading is studied (Tagliavia et al., 2010b). Therein, a computationally efficient approach based on an enriched Galerkin method is utilized to solve the set of governing integral equations. The method is similar to enriched finite element and meshless methods proposed in Ayhan et al. (2006), Ching and Batra (2001), Fleming et al. (1997), and Singh et al. (2010), where the basis set is enriched with special

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