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Effects of interphase formation on the modulus and stress concentration factor of fiber-reinforced thermosetting-matrix composites

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Abstract

Experimental and theoretical studies in the literature have shown that a fiber surface perturbs its surrounding polymer to create a three-dimensional interphase zone with property gradients. Micromechanical stress analysis and evaluation of the effective properties of composites need the interphase material properties as input information. Since relatively scant information is available on the prediction of interphase formation as function of processing conditions, current micromechanical analyses have resorted to using assumed interphase property profiles. In this paper, a thermodynamic model for interphase formation is adopted to predict the interphase material properties, which, in turn, are used in the finite element analysis of overall composite properties. Relevant numerical results are presented for the first time where two major composite properties, modulus and stress concentration factor, are directly linked to the interphase formation parameters without assumed structures or properties of the interphase. The results provide guidelines for selecting material components and processing parameters to achieve desired overall composite properties.
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1. Introduction

Fabrication of thermosetting-matrix composites is based on a critical step of cure, which involves applying predefined temperature cycle to a fiber–resin matrix mixture. The elevated temperatures initiate an irreversible crosslinking chemical reaction among the species in the matrix. The presence of fibers has been found to significantly influence the cure reaction, resulting in the formation of a third phase known as the interphase which possesses property gradient distinct from those of the bulk fiber and the matrix. The interphase resides in a region between the original constituents of the composite with a size of a few to a few thousand nanometers [1–4]. Although the region has a sub-microscopic scale, it directly influences the ability of the matrix to transfer load to the reinforcing fiber. The structure and properties of the interphase are therefore dominant factors governing the overall composite properties and performance.

Several physical and chemical mechanisms contribute simultaneously to the interphase formation and very few of them have been described rigorously in mathematical models. Garton et al. [5] showed that the carbon surfaces influence the cross-linking reaction in an anhydride–epoxy system by adsorbing the tertiary amine catalyst and forming amine rich interphase regions near the carbon surfaces. Similarly, Sellitti et al. [6] used Fourier transform IR attenuated total reflection spectroscopy to characterize the interphase phenomena in an epoxy–anhydride-catalyst system, and showed that the surface species introduced on graphitized carbon fibers can promote or inhibit the cross-linking process by the preferential adsorption of the catalyst. Other possible interphase mechanisms are proposed by Drzal [4].

The effects of interphase property gradients on the overall composite properties are extensively investigated in the literature [7–15]. However, the studies are commonly based on assumed or empirical interphase

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