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Cure Cycle Design for Thermosetting-Matrix Composites Fabrication under Uncertainty

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Abstract. Design of the optimal cure temperature cycle is imperative for low-cost of manufacturing thermosetting-matrix composites. Uncertainties exist in several material and process parameters, which lead to variability in the process performance and product quality. This paper addresses the problem of determining the optimal cure temperature cycles under uncertainty. A stochastic model is developed, in which the parameter uncertainties are represented as probability density functions, and deterministic numerical process simulations based on the governing process physics are used to determine the distributions quantifying the output parameter variability. A combined Nelder–Mead Simplex method and the simulated annealing algorithm is used in conjunction with the stochastic model to obtain time-optimal cure cycles, subject to constraints on parameters influencing the product quality. Results are presented to illustrate the effects of a degree of parameter uncertainty, constraint values, and material kinetics on the optimal cycles. The studies are used to identify a critical degree of uncertainty in practice above which a rigorous analysis and design under uncertainty is warranted; below this critical value, a deterministic optimal cure cycle may be used with reasonable confidence.

Keywords: design under uncertainty, sampling, stochastic model, optimization, composites fabrication, Nelder–Mead

1. Introduction

Fabrication of thermosetting-matrix composites is accomplished by subjecting the fiber-resin mixture to a prescribed temperature cycle in order to initiate and sustain irreversible cross-linking exothermic chemical reaction in the resin, called *cure*. This fabrication step is common to all the manufacturing processes including autoclave molding, pultrusion, and liquid molding techniques. The cure process transforms the initial mixture into a rigid structural component of which the structural integrity is retained upon the withdrawal of the external temperature variation. The magnitude and duration of the temperature variation, referred to as the cure temperature cycle, or in short, *cure cycle*, is one of the important process parameters affecting the final quality of the composite.

Design of cure cycles in practice has been based on trial-and-error or empirical procedure where either simulations utilizing physics-based process models, or experimental trials are carried out for several candidate cure cycles (Pillai, Beris, and Dhurjati, 1994; Loos and Springer, 1983; Han, Lee, and Chin, 1986; Bogetti and Gillespie, 1991;

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