Neural Network-Based Optimal Curing of Composite Materials

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Abstract: Polymer-matrix composites using thermosetting resins as the matrix are increasingly finding use in several applications. A widely-acknowledged impediment to their widespread commercial use is the high cost associated with their manufacture, arising from the long processing cycle times. Towards improving the manufacturing affordability of composite materials, several research efforts have been directed at the use of simulation models to obtain optimal cure cycles for the manufacture of composites. However, the computational tediousness associated with a rigorous numerical process simulation hampers the practical effectiveness of a numerical simulation-based optimization endeavor. With the objective of alleviating the computational tediousness, this paper presents the use of an artificial neural network in conjunction with a nonlinear programming technique for determining optimal cure cycles for the fabrication of thermosetting-matrix composites. The neural network is trained in terms of non-dimensional groups formed of the process and product parameters, which provides for better incorporation of the physical relationships among the parameters, for minimization of the training variables, and for generalization of the network training across material systems. Optimal cure cycles are reported for a wide range of practically-relevant processing conditions.

INTRODUCTION

THERMOSETTING-MATRIX composites fabrication is well-served by many continuous and batch processes such as pultrusion, autoclave curing, and resin transfer molding, among others, all of which share the common and critical step of cure. The cure step involves exposing the composite lay-up consisting of a multi-layered mixture of fibers and resin to elevated temperatures for a predetermined time duration which by means of an exothermic chemical reaction transforms the soft composite lay-up to a hard structural component. The magnitude and duration of the temperature variations, referred to as the cure temperature cycle, during the manufacturing process are important parameters influencing the cure and the product quality. The selection of an appropriate and furthermore optimal cure cycle for minimizing the fabrication time is therefore of great practical importance.

Selection of cure cycles in practice often relies on a trial-and-error procedure where either numerical models or experimental trials are used to investigate the fabrication process for several candidate cure cycles. Towards this end, most of the research efforts have been directed towards proposing/improving process models and assessing the effects of the process parameters on the cure [1–8]. The process design experience stemming from the trial-and-error approaches has led to the development of various rule-based strategies aimed at speeding up the cure process [9–11]. However, the trial-and-error approaches are expensive, and do not ensure the best possible process parameters. Furthermore, parametric studies using process simulation models, while useful for elucidating process characteristics, are an ineffective means of obtaining optimal process parameters especially in the presence of practical process constraints. As a result, in practice, proc-