

Rapid cure simulation using artificial neural networks

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Process simulations based on physical models describing the governing process phenomena have played an important role in improving the fundamental understanding and development of composites fabrication techniques over the last decade. In the several ongoing research efforts directed at improving manufacturing affordability of composite materials, simulation models offer great potential for tasks such as process optimization, robust process design, total quality manufacturing, and model-predictive on-line process control. However, the computational tedium associated with a rigorous numerical process simulation hampers the realization of the complete potential of simulation-assisted materials manufacturing, which calls for the simulation time scales to be comparable to those of the fabrication processes. Towards addressing this need, this paper presents the use of artificial neural networks trained using a physical process model as an effective substitute for rigorous numerical simulations in the simulation-assisted materials manufacturing endeavor. Considering the case of thermosetting-matrix composites fabrication, the use of neural networks trained and validated using the physical models is shown to increase the computational speed by several orders of magnitude. Further, network training in terms of non-dimensional groups formed of the process and product parameters is presented as an effective means of better incorporating the physical relationships among the parameters, generalizing the network training across material systems and product specifications, and reducing the number of training parameters. The accuracy of the neural network-based simulations is assessed for a wide range of practically relevant processing conditions. © 1997 Elsevier Science Limited.

(Keywords: composites curing; process simulations; neural networks; intelligent manufacturing)

NOMENCLATURE

C_{A0}	initial concentration of the resin (kg m^{-3})
E_1, E_2	activation energies in the kinetics model (kJ mol^{-1})
\bar{E}_1, \bar{E}_2	dimensionless activation energies
h	heat transfer coefficient (W K^{-1})
H_r	heat of the cure reaction (kJ kg^{-1})
k	thermal conductivity (W mK^{-1})
K_1, K_2	frequency factors in the kinetics model (s^{-1})
\bar{K}_1, \bar{K}_2	Damköhler numbers
m, n	empirical exponents in the cure kinetics model
N	number of patterns in the training set of the neural network
t	time (s)
T	temperature in the composite at any time t and spatial location, y
W	number of synaptic weights in the neural network
x, y, z	coordinate axes
α	thermal diffusivity = $k/(\rho C)$ ($\text{m}^2 \text{s}^{-1}$)
e	degree of cure
ρC	volumetric specific heat ($\text{kJ m}^{-3} \text{K}^{-1}$)

Subscripts

L	laminate
T	tooling
cure	cure cycle

INTRODUCTION

In the last decade, the use of laminated composite materials has increased considerably. Due to their light-weight and high-performance features, composites have found many widespread applications in modern industry. This increased demand for composites has led researchers in pursuit of better and faster methods of manufacturing composites.

Thermosetting-matrix composites fabrication, in particular, 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. The high temperatures initiate and sustain an exothermic chemical reaction which transforms the soft composite lay-up into a hard structural component. Evidently, the magnitude and duration of the temperature variations during the manufacturing process, referred to as the cure temperature cycle, are important parameters influencing the cure and the product quality.

Towards better understanding and designing the fabrication processes, several research efforts have been devoted

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